EFFECTS OF DIFFERENCING HEEL HEIGHTS ON THE LOWER LIMB BIOMECHANICS AND ENERGY PROFILES OF YOUNG THAI FEMALES DURING CONSTANT SPEED WALKING

CHUANPHIS BOONKERD

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ABSTRACT

The purpose of this study was to investigate the wearing of shoes with different heel height on ground reaction force, peak torque of hamstring and quadriceps and energy profile in young Thai females. The average aged was 18-22 years, weight about 47.59-53.91 kg., height about 160.23-160.53 cm. and BMI from 18.33-21.20 kg/m^2 .

Results revealed the deviation of the three component of ground reaction force (Fx, Fy and Fz). Whereas Fz_1, Fz_3, Fy_2, Fx_1 increased, Fz_2, Fy_1, Fy_3 decreased, depending on the height of heel (heel height 7.62, 6.35, 5.08 and 3.81 cm., but there was no significant difference in ground reaction force between each heel height and bare feet. 30 minutes walking with high-heel shoes affected on the strength of hamstring and quadriceps muscles, in which the peak torques of hamstring and quadriceps were decreased, but there was no significant difference between any heel height and bare feet walking. There was an increase in heart rate, oxygen consumption, carbon dioxide output and minute ventilation during walking with high-heel shoes. The increasing of energy profiles depends on the height of heel which were increased significantly higher during standing position. There were no significant difference between bare feet and high-heel shoes. The increasing of ground reaction force may affect the joint reaction force and may lead to degenerative joint change.

KEY WORDS: HIGH-HEELSHOES/ GROUND REACTION FORCE/ PEAK TORQUE / H/Q RATIO/ ENERGY

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ผลของความต่างของความสูงรองเท้าส้นสูงต่อการเปลี่ยนแปลงทางชีวกลศาสตร์ของระยางค์ส่วนล่างและการใช้พลังงานในวัยรุ่นไทยเพศหญิงขณะเดินด้วยความเร็วคงที่
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บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อศึกษาผลของผลของความสูงของรองเท้าส้นสูงต่อการเปลี่ยนแปลงทางชีวกลศาสตร์ของระยางค์ส่วนล่างและการใช้พลังงานในวัยรุ่นไทยเพศหญิงขณะเดินด้วยความเร็วคงที่ โดยผู้ถูกทดสอบมีอายุ 18-22 ปี. น้ำหนัก 47.59-53.91 กก. ส่วนสูง 160.23-160.53 ซม. และดัชนีมวลกาย 18.33-21.20 กก. ต่อ ตารางเมตร โดยการวัดการเปลี่ยนแปลงของแรงปฏิกริยาจากพื้น ความแข็งแรงของกล้ามเนื้อต้นขาทั้งก่อนและหลังการเดินด้วยเท้าเปล่าและรองเท้าส้นสูงและการใช้พลังงาน เพื่อนำไปอธิบายถึงการเปลี่ยนแปลงที่เกิดขึ้นจากการสวมใส่รองเท้าส้นสูงระดับต่าง ๆ กัน

ผลการศึกษาพบว่า ขณะเดินโดยสวมใส่รองเท้าส้นสูงมีผลในการเพิ่มแรงปฏิกริยาจากพื้นบางค่า (Fz_1,Fz_3,Fy_2,Fx_1) และบางค่าลดลง (Fz_2,Fy_1,Fy_3) โดยการเพิ่มและลดนั้นเปลี่ยนแปลงตามลำดับความสูงของส้นรองเท้า คือ 7.62 6.35 5.08 และ 3.81เซนติเมตร แต่ไม่มีความแตกต่างอย่างมีนัยสำคัญของแรงปฏิกริยาจากพื้นระหว่างรองเท้าส้นสูงแต่ละระดับและเท้าเปล่า ในการศึกษาผลต่อความแข็งแรงของกล้ามเนื้อต้นขาทั้งด้านหน้าและด้านหลัง หลังจากเดินด้วยรองเท้าส้นสูง 30 นาที พบว่าค่าความแข็งแรงของกล้ามเนื้อต้นขาทั้งด้านหน้าและด้านหลังลดลง โดยลดลงตามลำดับความสูงของส้นรองเท้าแต่ไม่มีความแตกต่างอย่างมีนัยสำคัญของความแข็งแรงของกล้ามเนื้อต้นขาทั้งด้านหน้าและด้านหลังระหว่างรองเท้าส้นสูงแต่ละระดับและเท้าเปล่า และในการใช้พลังงานพบว่าขณะเดินด้วยรองเท้าส้นสูงมีการใช้พลังงานเพิ่มขึ้น โดยเพิ่มตามลำดับความสูงของส้นรองเท้าและมีความแตกต่างอย่างมีนัยสำคัญเมื่อเปรียบเทียบกับท่ายืน โดยการเพิ่มขึ้นของแรงปฏิกริยาจากพื้นอาจส่งผลต่อแรงปฏิกริยาในข้อต่อ ซึ่งอาจนำไปสู่การเสื่อมของข้อต่อได้

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A-P GRF	anterior-posterior ground reaction force
BMI	body mass index
BW	body weight
bpm	beat per min
cm	centimeter
CO_2	Carbon dioxide
Fx_1	first peak of anterior-posterior ground reaction force
Fx_2	second peak of anterior-posterior ground reaction force
Fy_1	first peak of medial-lateral ground reaction force
Fy_2	second peak of medial-lateral ground reaction force
Fy_3	third peak of medial-lateral ground reaction force
Fz_1	first peak of vertical ground reaction force
Fz_2	vertical ground reaction force
Fz_3	second peak of vertical ground reaction force
GC	gait cycle
GRF	ground reaction force
H/Q	hamstring/quadriceps
HR	heart rate
Ht	body height
J	joule
Kg	kilogram
Km	kilometer
l	liter
m	meter
max	maximum, maximal
min	minute
M-L GRF	medial-lateral ground reaction force

LIST OF ABBRIVIATIONS (CONT)

ml	milliliter
Nm	Newton-meter
O_2	oxygen
RER	respiratory exchange ratio
SD	standard deviation
sec	second
SEM	standard error of the mean
$V^{?}CO_2$	Carbon dioxide output
$V^{?}E$	minute ventilation
$V^{?}O_2$	oxygen consumption
yrs	year

CHAPTER 1

INTRODUCTION

Most women wear high-heel shoes in both working hours and social period. Because of the anatomical arrangement of human lower limbs, additional device may alter the normal physiological alignment of the foot, knee and hip. Walking with high-heel shoes may cause stress, causing changes in the normal contribution of the lower extremity. These changes may lead to the risk of musculoskeletal problems such as low back pain or injury, knee, ankle and foot pain. Also changes of spinal lumbar curve and alteration of tissue stress patterns that may contribute to the lower back symptoms (25,31,65,66). Knee pain can occur as a result of prolonged strain, compressive force (45) and hyperflexion or hyperextension of knee during high-heel gait (25,65,66). The reasons for these alterations may be due to additional weight placed on the forefoot (49) also forefoot walking pushed means CM (Center of mass) forward placing more stress on foot impact and instability of walking which produces ankle pain (66). In contrast to these studies, Dawson and co-workers in 2002 (20) indicated that foot problems were significantly associated with a history of wearing relatively lower heels. It is postulated that high-heel shoes may have an affect on biomechanical walking patterns as well as body's energy expenditure.

Previous studies have indicated various effects of high-heels shoes on posture (31,49,65,66,79). Snow and Williams in 1994 (79) reported that wearing high-heel shoes increased foot supination at foot strike and ankle plantarflexion during high-heel gait. These may be due to more anterior displacement of the center of mass (CM). It is shown that there are reductions in hip external rotation during heel strike, hip abduction during toe off, hip flexion and knee flexion during swing phase (66). Previous studies reported the changes of posture during high-heel gait with controversial results. Some studies found that wearing of the high-heel shoes caused increasing in lumbar lordosis (49,65). Lee and co-worker in 2001 (49) studied the effects of wearing high-heel shoes on biomechanics. In this study, subjects had no experienced in wearing high-heel shoes, whereas shoes had three heel height conditions (0 cm.,4.5 cm.,8 cm.). They found that trunk flexion decreased significantly as heel height increase. Opila-correia in 1990 (65) studied effect of high-heel shoes on experienced and inexperienced young and older wearers. By the young subjects had increased lumbar lordosis during high-heel gait, whereas older subjects had flattened trunk. In experienced wearers had greater knee flexion during stance phase than inexperienced wearers. In contrast to these studies, Franklin and co-worker in 1995 (31), studied postural change during walking with high-heel shoes. Subjects had no experienced of wearing high-heel shoes with heel height about 5.1 cm. They found that posture during standing with positive heel inclination decreased lumbar lordosis, sacral base angle and anterior pelvic tilt when compared to standing with zero heel inclination. Whereas Snow and William in 1994 (79) had studied in experience wearers with heel height 1.91cm., 3.81 cm. and 7.62 cm. They found progressively changes in lumbar lordosis (15,79).

Few studies analyzed the kinetic variables of high-heeled gait (25,44,45,61,79). Wearing of high-heel shoes induced a greater vertical ground reaction force and anterior-posterior ground reaction force (25,79). The first maximum force, percent time to first maximum force, minimum force, and the percent time to minimum force were a significant difference between the highest and the three lower heel heights. One anterior-posterior ground reaction force while walking in the flat or 1.25-cm heel shoes was less than those in the three higher heel heights. With an increase in heel height, the minimum vertical ground reaction force (at mid stance) and the maximum vertical ground reaction force (during the second half of support) occurred later in support phase, whereas the maximum and minimum anterior-posterior forces occurred earlier (79).

Few studies analyzed the energy cost of walking with high-heel shoes. Ebbeling and co-workers in 1994 (25) studied changes in lower extremity mechanics and energy cost of walking on treadmill with high-heel shoes in experienced and inexperienced wearers at a walking speed of 4 km/hr. Metabolically, heart rate and oxygen consumption also increased with high-heeled gait. By heart rate, oxygen consumption and carbon dioxide output were a significant difference between the highest heel height and the three lower heel heights. There was no significant difference in any of the parameters comparing experienced wearers and inexperienced wearers.

Chinkulprasert in 1997 (15) studied the postural changes during standing and changing lumbar curvature and pelvic tilting during walking with different heel height in young Thai female subjects. The result showed that there were increases in neck flexion, knee flexion, and ankle plantarflexion during high-heeled stance. For high-heeled gait, there were no significant differences among heel heights neither in lumbar angle nor pelvic tilt angle.

Nuntapornsak in 2002 (61) studied the postural changes and ground reaction force during walking with high-heeled shoes in experienced and inexperienced wears. Lumbar lordosis decreased during high-heeled gait in both groups. In inexperienced wears, there was no significant difference in pelvic tilt between bare feet and high-heeled gait. There were increases in hip flexion, knee flexion, and ankle plantarflexion, and supination during high-heeled gait. Increasing in the first peak of vertical ground reaction force and braking force were found in inexperienced group during high-heeled gait. Whereas there were decreasing in the first peak of medial-lateral ground reaction force, third peak of medial-lateral ground reaction force and propulsive force during high-heeled gait. In experienced group, there were increases in first peak of vertical ground reaction force, second peak of medial-lateral ground reaction force and braking force were found high-heeled gait. Whereas there were decreasing in vertical ground reaction force at mid stance, third peak of medial-lateral ground reaction force and propulsive force during high-heeled gait. In Thailand, there was investigation of energy cost during walking with high-heel shoes. Thus, the significant of high-heel shoes were studied reportedly in different models in both overseas and Thailand. As the Thai lifestyle is being changed, the present study focuses, within the same model, on comparing ground reaction force, peak torque of hamstring and quadriceps and oxygen consumption during walking between bare feet and differencing heel height (15,61).

Purposes of the study

This study is aimed to investigate changes in biomechanical function of the feet when wearing different heel heights shoes and assesses the energy expenditure involved.

General objectives

To compared vertical ground reaction force, medial-lateral ground reaction force and anterior-posterior ground reaction force by walking 4 km/hr in walkway and oxygen consumption by walking on treadmill at 4 km/hr between different heel heights, hamstrings/quadriceps strength and the peak torque of hamstring and quadriceps on isokinetic dynamometer at 60 radius/sec after walking on treadmill with bare feet, and differencing heel height.

Specific objective

1. To compare the vertical ground reaction forces, medial-lateral ground reaction forces and anterior-posterior ground reaction forces during walking with bare feet and shoes with different heel heights at constant speed.
2. To assesse the isokinetics of h/q ratio, peak torque of hamstring and quadriceps after walking with bare feet and shoes with differencing heel height.
3. To measured heart rate, oxygen consumption, carbon dioxide output , respiratory exchange ratio and minute ventilation during constant speed walking on treadmill with bare feet and shoes with differencing heel height.

Hypothesis

1. Walking with different high-heel shoes will affect the vertical ground reaction forces, medial-lateral ground reaction force and anterior-posterior ground reaction force.
2. There will be significant differences in hamstrings/quadriceps ratio, peak torque of hamstring and quadriceps between bare feet and different high-heel shoes after walking with constant speed.
3. Total body energy expenditure and efficiency will be affected with the height of shoes.

Parameters

The following parameters were investigated in this study.

1. Ground reaction forces
    - 1.1 Vertical ground reaction force
    - 1.2 Anterior-posterior ground reaction force
    - 1.3 Medial-lateral ground reaction force
2. Isokinetics data
    - 2.1 Hamstring/ quadriceps ratio
    - 2.2 Peak torques of hamstring and quadriceps
3. Energy cost
    - 3.1 Heart rate
    - 3.2 Oxygen consumption
    - 3.3 Carbon dioxide output
    - 3.4 Respiratory exchanges ratio
    - 3.5 Minute Ventilation

Scope of the study

This study compared ground reaction forces, hamstring/quadriceps ratio, peak torque of hamstring and quadriceps and oxygen consumption during a constant walking speed with bare feet and shoes with different heel heights. All subjects were females with aged from 18 to 22 year. Ground reaction forces during walking were measured by using AMTI force platform. A Lido Multi joint isokinetics dynamometer measured hamstring/quadriceps ratios and peak torque of hamstring and quadriceps. Oxygen consumption and energy profiles were detected by using Vmax 229.

Usefulness of the study

This study may provide the information for better understanding on normal gait cycle and energy consumption as well as the biomechanical changes in walking with different shoe heights. The information gained from this study indicates the effect of wearing high-heel shoes on abnormality of ground reaction force.

CHAPTER 2
LITERATURE REVIEW

2.1 Biomechanics of human walking cycle

Normal gait is a complex phenomenon spontaneous learning (61). Walking is the highly complex motor skill that incorporates input from multiple levels of the nervous system and involves muscular contributions throughout the body. Apart from dynamic body balance, it also requires the coordination of many skeletal degrees of freedom (56). Foot is essential part during upright human locomotion, dynamic connection between the human body and the ground and the human foot is mark able in the way to adapt successfully function on such variety terrain. There are differences in walking patterns between children, adults and old persons (41,56,67). Gait cycle has been defined as "the movements and events that occur between successive heel contact of the same foot" (71). The gait cycle, in its simplest form, is comprised of stance and swing phases. Stance phase is the period when foot contacts with the ground and supporting the body's weight. This phase accounts for about 60 percent of the gait cycle at normal walking speed. The remaining 40 percent of gait cycle is swing phase, which is the period when the foot is in the air being advanced forward for the next contact with the around (46,71). In the gait cycle, it has two sub-periods of double-limb support in which both feet are in contact with the ground simultaneously and two periods of single-limb support by only foot contact with the ground. Duration of the first period of double-limb support is about 10 percent of gait cycle. After that, body weight is being transferred from the left foot to the right foot. This is the first period of single-limb support takes between 10-50 percent of gait cycle. Which, the left foot is in swing phase, being to forward. This is the second period of double-limb support take place between 50-60 percent of gait cycle and serve the transferring the weight from the right foot to the left foot. After that, this is the second period of single-limb support, from 60-100 percent of gait cycle. The left foot supports the body weight. This phase corresponds to the swing phase of the right foot (46). The time and phase of gait cycle are shown in Figure 1.

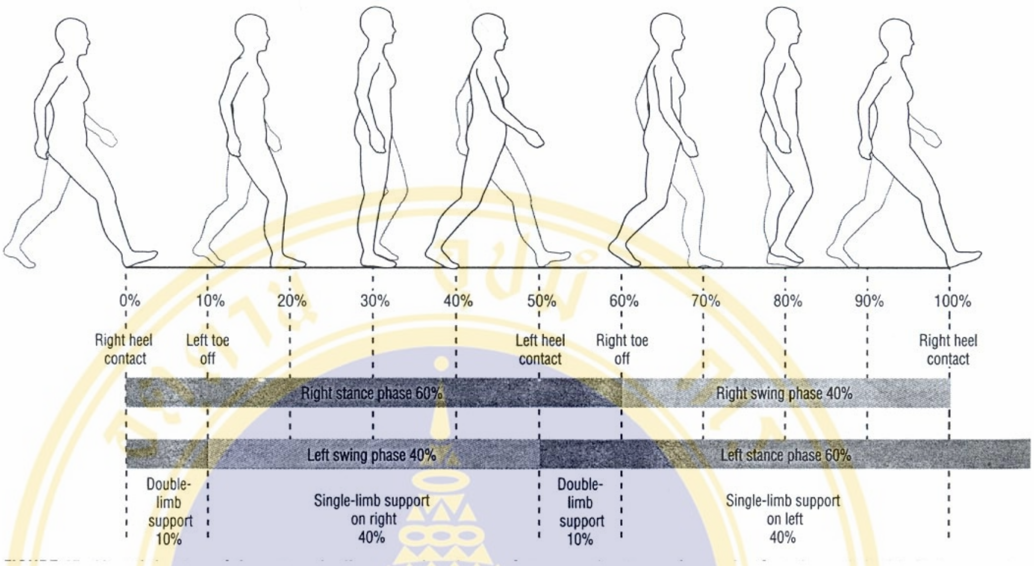

Figure 1 The time and phase of gait cycle

The subdivision of gait cycle has eight events. By in stance phase has five events (heel strike, foot flat, mid stance, heel off and toe off) and in swing phase has three events (early swing, mid swing and late swing). The common terminology define subdivisions of gait cycle had shown in Table 1.

Table 1 Common terminology defines subdivision of gait cycle.

Phase	Event	Percent of gait cycle	Event of opposite limb
Stance	Heel contact	0	
	Foot flat	8	
		10	Toe off
	Mid stance	30	Mid swing (25-35 percent of gait cycle)
	Heel off	40	
		50	Heel contact
	Toe off	60	
Swing	Early swing	60-75	
	Mid swing	75-85	Mid stance (80 percent of gait cycle)
	Late swing	85-100	
		90	Heel off
	Heel contact	100	

In stance phase, the heel strike is defined when the heel comes in contact with the ground. Foot flat corresponds to the entire plantar surface of foot which comes to contact with the ground. In mid stance is defined as the point of the body's weight passes directly over the support lower extremity. Heel off is when the heel comes off the ground and the toe off when the toes come off the ground. In swing phase, the early swing is the period from the time of toe off to mid swing and the mid swing corresponds to the mid stance event of the opposite lower extremity when the foot of the swing leg passes movement to the foot of stance leg. Whereas, the late swing is the period from the mid swing to the foot contact with the ground (46). The events of gait cycle are presented in Figure 2.

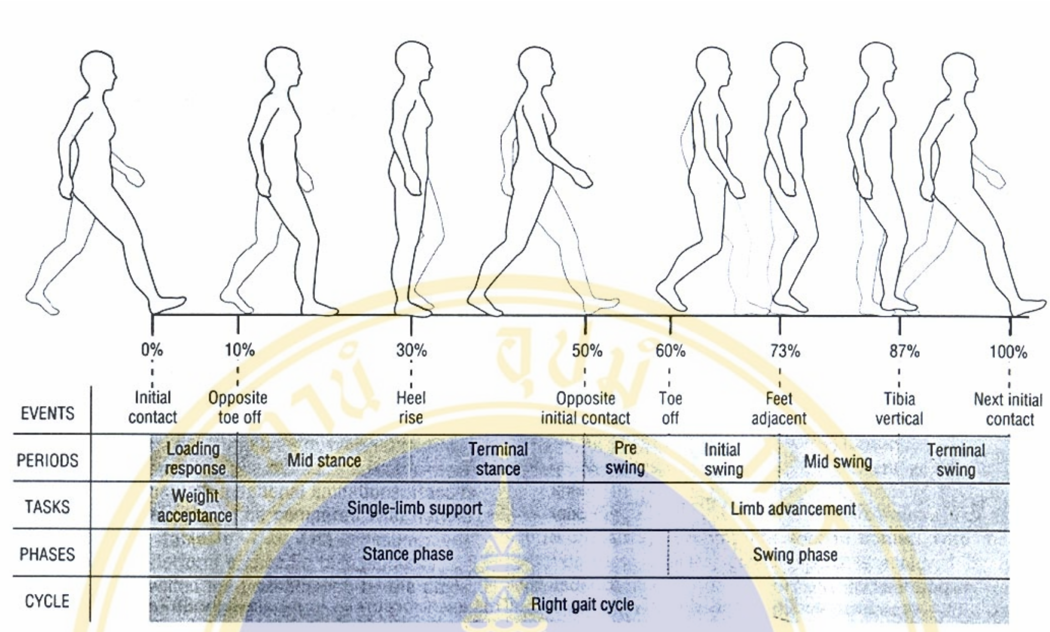

Figure 2 The events of gait cycle.

2.1.1 Gait characteristics

Temporal and distance parameters of a stride consist of the movement of both limbs during a gait cycle and contains two steps. Stride length is the distance between ground contact of one foot and the subsequent ground contact of the same foot. Whereas, a step is operationally defined as the movement of a single limb from ground contact of the opposite limb (64). Stride and step lengths depend directly upon standing height, so measures of absolute step or stride length, although frequently reported, are difficult to interpret. These measures can be normalized by standing height or lower extremity length to compare values from difference individual (53,64). Estimation of normalized stride length varies from approximately 30 to 110 % of standing height (64). Step width and foot angle are less frequently reported but provide an indication of the size of the base of support. Step width is the lateral distance between the heel center of two consecutive foot contacts and normally range from 7 to 9 cm.(46). Whereas, the foot angle is the degree of toe out and the angle between the line of progression of the body and the long axis of the foot. The normal ranges about 7 degrees (46). The spatial descriptors of gait cycle is demonstrated in Figure 3.

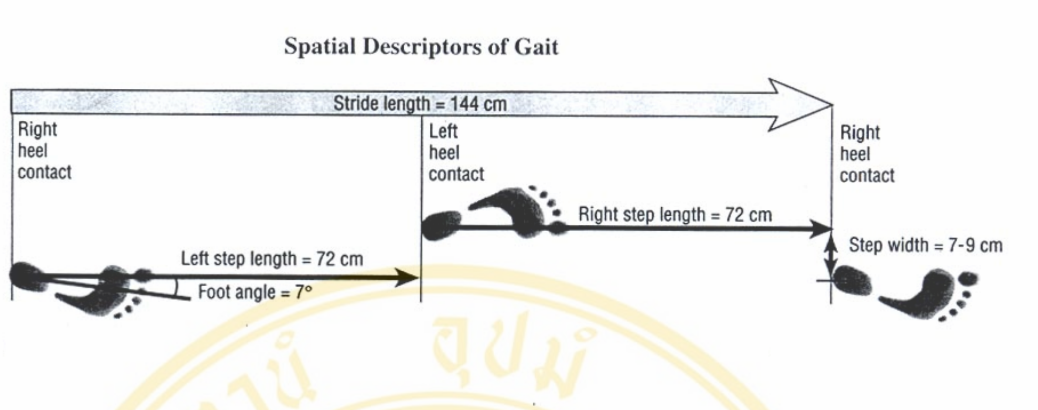

Figure 3 The spatial descriptors of gait cycle

The temporal characteristics of the stride such as speed, stride time, cadence. The normal gait cycle at free speed lasts approximately 1 second, and walking speed is between 3 and 4 miles per hour (mph). Walking speed is a function of both cadence (step/minute) and step length. During normal speed walking, the cadence is about 110-112 step per minute (35). An increased in either cadence or step length contributes to increased walking speed (37,40). Increasing walking speed decreases the over all duration of the gait cycle, but the decrease in cycle duration results in a greater decrease in stance time than in swing time (37). Walking speed varies considerably between persons based on factors such as age and physical characteristics such as height and weight (46). Of all spatial and temporal measurements of gait, speed may be the best and most functional measure of an individual 's walking ability. Summary of the temporal-distance variables in normal subjects are show in Table 2

Table 2 Review on gait characteristic.

Authors	Jansen and co-worker 1982 (16)	Gabel and co-worker 1984 (24)	Banke and co-worker 1986 (25)	Winter and co-worker 1990 (26)	Sekiya and co-worker 1997 (27)
Sample sizes	10 10 10 10	32 32	12 12	12 15	12 10
Age (yrs)	22-29 20-29 60-69 60-69	21-47 68-84	20-33 60-67	24.6 68.0	19-22 20-30
Sex	F M F M	F-M F-M	M M	F-M F-M	M F
Speed (m/sec)	1.10 1.10 1.10 1.10	Free Free	Free Free	Free Free	Free Free
Cadence (step/min)				111.0 110.5	106.4 108.4

- Speed = speed of test

Authors	Jansen and co-worker 1982 (16)	Gabel and co-worker 1984 (24)	Banke and co-worker 1986 (25)	Winter and co-worker 1990 (26)	Sekiya and co-worker 1997 (27)
Velocity (m/sec)	1.10 1.12 1.08 1.11	1.37 1.19	1.31 1.39		1.23 1.39
Stride length (cm)	97 105 92 103		192.6 189.6	105 139	
Step length (cm)	48.5 52.5 46 51.5	76 64	87.6 94.2		69.5 76.0
Step width (cm)		8.0 10.0	10.8 8.3		7.0 9.0
Cycle time (sec)		1.10 1.08			
Stance phase (%GC)*	69 69 69 69		62.3 65.5		

Table 2 Review on gait characteristic (CONT).

- % GC = percent of gait cycle

Table 2 Review on gait characteristic (CONT).

Authors	Jansen and co-worker 1982 (16)	Gabel and co-worker 1984 (24)	Banke and co-worker 1986 (25)	Winter and co-worker 1990 (26)	Sekiya and co-worker 1997 (27)
Swing phase (%GC)	31 31 31 31				
Double phase (%GC)*	36 36 37 37	24 24		24.6 32.0	

* % GC = percent of gait cycle

In 1996, Eisenhardt and co-workers (26) studied the change in temporal gait characteristic for bare feet versus various heel heights. They concluded that, the stance phase was shortened in shoes, and the percentage of stance spent in weight bearing on the lateral and medial calcaneous decrease above a 3.12 cm heel height, whereas when wearing shoes on the forces on the first and second metatarsal heads increased. The percentage of stance spent in weight bearing on the fifth metatarsal was less in the 8.74 cm heel shoes than in bare feet.

Jansen and co-worker in 1982 (41) studied normal gait of young and old men and women on the treadmill. By the young men and women age from 20-29 years and in old men and women age from 60-69 years. Subjects walked on treadmill at a constant speed of 4 kilometer per hour. Subjects were measured the stride length, ataxia or unsteadiness of gait and ground reaction force. They found stride length of elderly women decreased significant difference from elderly men. A similar difference was found between young women and young men. Whereas in total ataxia had greater in young women than young men and old women than old men. On other parameter showed any significant difference either between men an women, or between younger and older persons.

2.1.2 Ground reaction forces of gait

During walking, the foot is in contact with the ground, such impact ground reaction force. Ground reaction force (GRF) is equal in magnitudes but opposite in direction to the applied from weight-bearing limb. (Newton 's Third Law- the law of action and reaction – states that forces are always present in pair that are equal in magnitude and opposite in direction.) These ground reaction force is the reaction force acting on the body during walking. It is further subdivided into 3 components 1.vertical ground reaction force 2.medial-lateral ground reaction force 3.anterior-posterior ground reaction force (69,71) (Fig 4).

The ground reaction force is measured by a force platform. A force plate consists of a Piezo-electric load-sensitive surface set into a walkway that measures the changing force imposed on it during the period of foot contact (47). During walking, the force produced by stance foot on the force platform is recorded. The electrical output signals produce three spatial place of force. The length of vector represents the quantity of applied force that is normalizing by body weight (%BW). The direction of the vector opposes to the direction of the applied force (71).

The vertical ground reaction is directed perpendicular to the supporting surface. Vertical ground reaction force has three characteristics. The first peak (Fz_1) occurs at the onset of mid stance in response to the weight-accepting event during loading response. At this time the body's center of gravity is rapidly dropping, an action that adds the effect of acceleration to body weight. The vertical ground reaction force goes to maximum of 110-120 %BW. The vertical ground reaction force (Fz_2) drops to 80%BW during mid stance. Because the valley is created by the rise of the center of gravity as the body rolls forward over the stationary foot.(Force is a function of mass as well as acceleration ;F=ma). The second peak (Fz_3) is the force occurring in late terminal stance, again indicated downward acceleration and lowering of the center of gravity as body weight falls forward over the forward foot rocker in terminal stance through pre swing and goes to maximum of 110-120 %BW (69,71) (Fig 5)

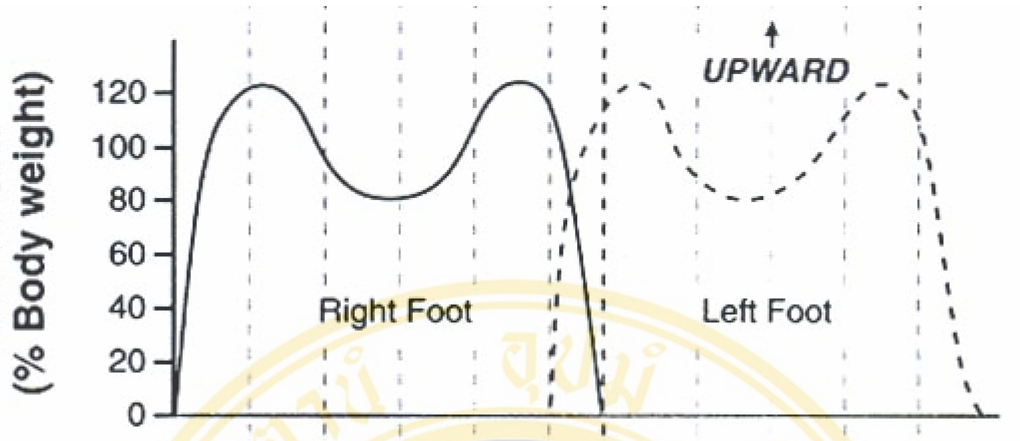

Figure 5 The vertical ground reaction during walking

The medial-lateral ground reaction force relates to balance of the body during walking. The magnitude of force is about 5-7 %BW. The peak medial-lateral ground reaction force initially acts in the lateral direction (Fy_1) during loading response. By the laterally direction ground reaction force shear force is produced to step the small lateral-to-medial velocity of the foot. Then, the peak medial-lateral ground reaction force acts in the medial direction (Fy_2, Fy_3) during terminal stance (47,69). Because the center of mass of the body is medial to the foot, causing a laterally directed force to be applied to the ground by the foot and a medially directed ground reaction force (Fig 6).

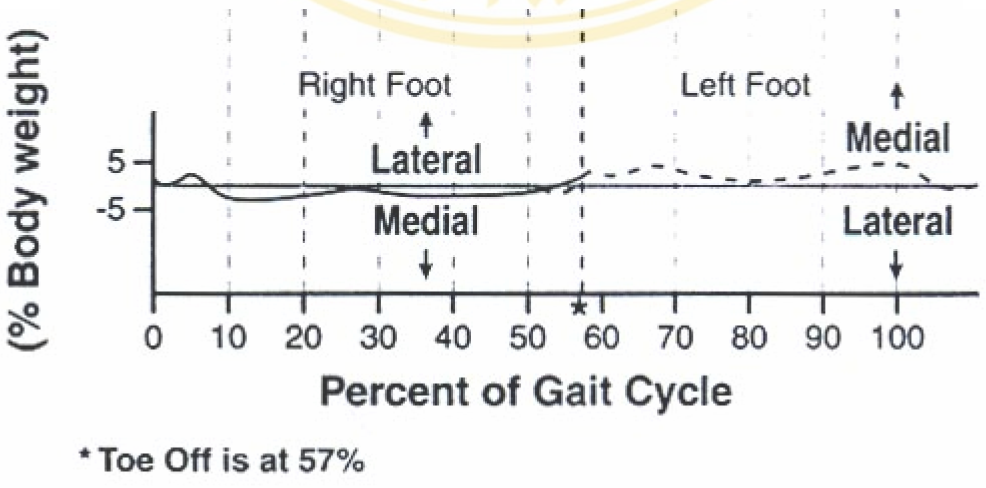

Figure 6 The medial-lateral ground reaction force during walking

During terminal stance and pre swing, the ground reaction force is directed anteriorly, with the foot applying a posteriorly directed force to the ground in order to propel the body forward. The magnitude of the propulsive force depends on walking speed and attempts to accelerate. The peak anterior-posterior ground reaction force is typically equal to about 20% of body weight. These shear force are in large part the result of the center of mass of the body's being either posterior (at heel contact) or anterior (at pre swing) to the foot. The larger step length has a greater shear force because of the greater angle between the lower extremity and the floor. Inertial properties of the body, such as momentum, also contribute the anterior-posterior ground reaction force. The first break (Fx_1) is braking force occur in loading response and the second peak force is propulsive force (Fx_2). The breaking force should be approximately equal to the propulsive force in order to balance the gait (69) (Fig 7).

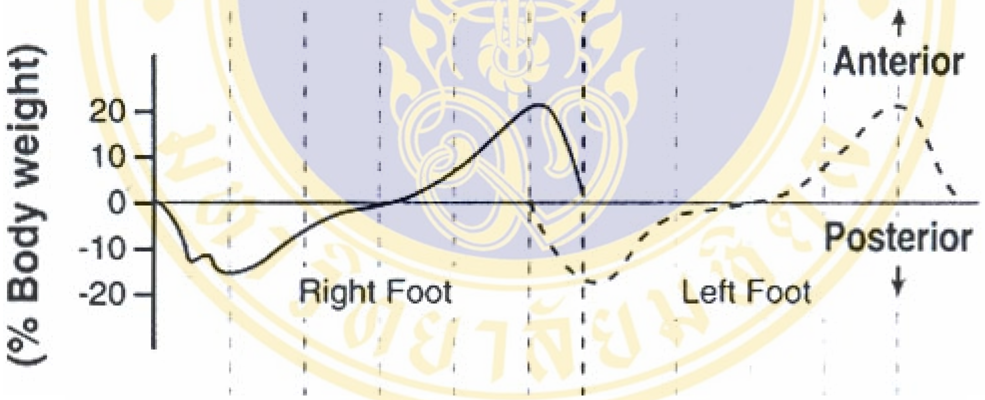

Figure 7 The anterior-posterior ground reaction during walking

In 1996, Keller and co-workers (42) reported the relationship between vertical ground reaction force and speed during walking, slow jogging, and running. All subjects were recreational athletes (basketball, squash, cycling, soccer, racquetball, distance running and other sports). They compared the vertical ground reaction force between four walking speeds (1.5, 2.0, 2.5, 3.0 m/s) and four running speed (3.5, 4.0, 5.0, 6.0 m/s) in twenty-three subjects by using force platform. In both male and female subjects, maximum ground reaction force increased linearly during walking and running from 1.2 of body weight to approximately 2.5 of body weight at higher speeds. Maximum ground reaction force was linearly correlated to loading rate, the latter ranging from 8 to 30 of body weight per sec over this speed range (42).

In 1999, Simpson and Jiang (78) evaluated about foot landing position during gait influences ground reaction force. All subjects were assigned to a foot landing group (toe in, toe out or neutral). They found that, no difference for vertical and anterior-posterior ground reaction force variables between toe-out, toe-in and neutral. For medial-lateral ground reaction force, toe-out participants exhibited greater first lateral and second medial maximum force and exhibited greater impulse.

2.2 High-heel gait.

Ebbling and co-workers in 1994 (25) studied effect of different heel heights on the biomechanics and energy cost of gait. In this study, they used force platform to collect the ground reaction force data in fifteen young females during high-heel gait with different heel height (1.25,3.81,5.08,7.02 cm) between experienced and inexperienced wearers and subject walked on over ground and on treadmill at 4.2 kilometer per hour. In highest heel has an increase in both vertical and anterior-posterior ground reaction force. Contrast, the second peak vertical force and medial-lateral ground reaction force decreased during high-heel gait.

Esenyel and co-worker in 2002 (27), they studied about high-heel shoes alter low extremity kinetic function and work distribution. This study had two groups (low and high-heel shoes) by the low heel about 1 cm. and high-heel about 6 cm. Subjects were wearer high and low heel shoes. These change represent adaptive strategies that maintain limb stability as the ankle is force into a exaggerated plantar flexed posture and substitute for reduced plantar flexor function in limb advancement through the increased use of hip flexor activity. The change appear to be capable or creating abnormal and potentially injurious force that may underline some of the proximal joint and spine pain complaints of high-heel shoes users.

Kerrigan and co-worker in 2001 (44) assessed whether wearing wide heeled shoes has a similar effect on knee torque to narrow heeled shoes by measuring the joint torque during walking. The heel height about 7.0 cm., whereas the narrow base shoes were an average 1.2 cm. in width and wide base were 4.5 cm. in width. Subjects walked bare feet and each pair of shoes at comfortable walking speed. By wearing wide and narrow heeled shoes had a greater effect on peak external knee flexor torque than walking bare feet. Their finding imply high-heel shoes cause abnormal force across the patellofemoral joint and medial compartment of knee, which are a degenerative joint change. This possibility is pertinent, because osteoarthritis is twice as common in women as in men (45). Osteoarthritis change are more common in the medial than in the lateral aspect of knee because during walking in high-heel shoes shift the weight of body medially with respect to the foot (26,63). A greater varus torque implies a greater compressive force on the medial aspect of knee.

Nuntapornsak in 2002 (61) studied the postural changes and ground reaction force during walking with high-heeled shoes in experienced and inexperienced wears. Increases in first peak of vertical ground reaction force and braking force were found in inexperienced group during high-heeled gait. Whereas there were decreases in first peak of medial-lateral ground reaction force, third peak of medial-lateral ground reaction force and propulsive force during high-heeled gait. In experienced group, there were increases in first peak of vertical ground reaction force, second peak of medial-lateral ground reaction force and braking force during high-heeled gait. Whereas there were decreases in vertical ground reaction force at mid stance, third peak of medial-lateral ground reaction force and propulsive force during high-heeled gait.

Snow and William in 1994 (79) studied effect of high-heel shoes on center of mass position, posture, three-dimensional kinematics, rear foot motion, and ground reaction force. All subjects had worn high-heel shoes at least 1 year. These criteria were established to minimize variation to wearing high-heel shoes. They used a force platform to determine the displacement of position of center of gravity and ground reaction force (vertical, medial-lateral, anterior-posterior) in eleven females at 1.4m/s walking speed in different heights of high-heel shoes (1.19, 3.81, 7.62 cm). Peak of vertical and anterior force during loading response was greater in high-heel gait. Time at second peak force of vertical direction occurred a later in support phase of high-heel gait. Peak force of anterior direction occurred later in the stance phase in the low-heel relative to medium and high-heel.

Stefanyshyn and co-workers in 2002 (81) investigated the influence of high-heel shoes on kinematics, kinetics, and muscle EMG of normal female gait. They used force platform to determine ground reaction force in thirteen females. All subjects regularly wore high-heel shoes during their workday. The average heel heights of the four shoes were 1.4 cm.,3.7 cm.,5.4 cm. and 8.5 cm. They wore high-heel shoes and walked on walkway at 1.4±0.2 meter per sec. High heel resulted higher ground reaction force in the anterior and posterior direction. The increased anterior-posterior force corresponded to in the peak deceleration and acceleration force in the vertical direction. The maximal vertical impact force and the maximal vertical impact-loading rate were significantly higher for both the 3.7 cm and 5.4 cm than either the flat or 8.5 cm The highest shoes had the lowest value of the maximal vertical impact force and the maximal vertical impact-loading rate.

2.3 Hamstrings/ quadriceps ratio.

Isokinetics dynamometry was utilized for assessing the performance of voluntary muscles. Unless, the physiological and biomechanical factor, the psychological factor are involved. So, the cooperation is necessary component for testing. The basic relationships of muscle performance are the length of muscle and the magnitude of tension. By the muscle length to the maximal active tension is resting length. Because of, the amount of the tension developed is related to the number of cross bridge between the actins and myosin filament.

Isokinetic dynamometry is concerned with the provision of this resistance and the measurement of the moment exerted by the muscle against the resistance whereas constant angular velocity (17,24). Isokinetics scores have commonly been reported in absolute unit such as Newton meters (Nm) of torque and joules (J) of work accomplished, but data have also been reported as rations in relation to body weight or joint movements (17). Strength has been described as the “force or tension a muscle can exert against the resistance in one maximal effort” (17). One of the most reliable method of is measuring strength is using hamstring/quadriceps ratio (h/q ratio).

In clinical studies, some authors have reported the importance of the agonist-antagonist torque ratios (3,10,14,80) and the role of contraction of agonist and antagonist muscles in maintaining joint stability (3,14,80). The ratio of knee flexion strength (hamstrings) to knee extension strength (quadriceps), the so-called h/q ratio, is an established method to assess relative strength of the muscle groups (6,77).

The h/q ratio is operationally defined as the peak isokinetics torque of the hamstring muscles divided by that of the quadriceps muscles, multiplied by 100 (35). The h/q ratio of 60 percent has been accepted for slow-speed isokinetics movement.

In clinical, the isokinetic dynamometer used to evaluation the patient with total knee arthroplasty. By Berman and co-worker in 1991 (6), they studied effects of total knee arthroplasty on the function of the knee by compare involved and uninvolved knee joint and preoperative and postoperative total knee arthroplasty. In preoperative testing, they had extension and flexion test of both side and they were performed at a speed of 60 degree per sec. Whereas, in postoperative testing were grouped according to the time period of 6 post operative month or less, 7 through 12 postoperative months, 13 through 23 postoperative months and greater than 24 postoperative months. In preoperative, they found the peak torque in flexion of involved about 68 percent from uninvolved knee, whereas peak torque in extension was just more than one-half of the contra lateral of extremity (59 percent). In postoperative, they found the peak torque hamstring and quadriceps in 24 postoperative months had greater than 13 through 23 postoperative months, 7 through 12 postoperative months and 3 through 6 postoperative months. But the hamstring peak torque value were able to attain strength levels of the uninvolved within 7 through 12 month after surgery, where the quadriceps still showed residual deficit at two years follow up. Whereas, the h/q ratios of involved and uninvolved knee had about 56.98 and 55.91 at 24 postoperative months. So the hamstring and quadriceps exercise were necessary rehabilitation program for total knee arthroplasty patient for resumption of normal gait.

Calmels and co-worker in 1997 (14) studied about the relationship between the flexor/extensor torque ratio in the hip, knee and ankle. Subjects in this study were males and female between age 18 and 40 years. The test at a joint consisted of three concentric exercises at 60 degree per sec, 120 degree per sec and 240 degree per sec and three eccentric exercises of 60 degree per sec and 120 degree per sec. They found no significant difference between the flexor-extensor torque ratio on the left and right side for the knee and knee at all angular velocities in concentric and eccentric mode. Any the flexor/extensor torque ratios differenced significantly according to sex and angular velocities but not according to side expect for ankle. No significant relationship was found the flexor/extensor toque ratio in hip, knee and ankle.

In 1996, Croce and co-workers (17) studied about peak torque, average power and hamstring/quadriceps ratios in disabled adults and adults with mental retardation. By, this study compared peak torque, power and h/q ratio between the men with Down syndrome, with mental retardation but without Down syndrome and no disabled sedentary control. They were performed concentric contraction of hamstring and quadriceps at 60 degree per sec and 90 degree per sec. In all isokinetic parameters measured, sedentary controls demonstrated significantly higher scores than subjects with Down syndrome and subjects with mental retardation without Down syndrome. However, individuals with mental retardation are indeed of progressive resistance exercise program to improve hamstrings and quadriceps strength and normalize hq strength and power ratios.

Ghena and co-worker in 1991 (35), they studied about torque characteristics of the quadriceps and hamstring muscles during concentric and eccentric loading. All subjects were male varsity athletes between age of 18 and 25 years. Subjects were tested on isokinetics dynamometer concentrically at 60, 120, 300 and 450 degree per sec and eccentrically at 60 and 120 degree per sec about three maximal contractions in each condition. Concentric torque production of the quadriceps and hamstring muscles decreased significantly as the angular velocity increased. Torque production of the quadriceps and hamstring muscles was significantly greater during eccentric than concentric loading. The concentric h/q ratios increased significantly as the angular velocity increased. H/q ratios were significantly greater during eccentric than concentric loading.

Sharp and Broumer in 1997 (76) studied about effect of isokinetic strength training on function and spasticity of the hemiparetic knee. They studied in hemiparalysis subjects. They had residual weakness or spasticity of they affected lower extremity. They were at least 6-month post stroke, were independently ambulatory with or without aids over 12-meter distance. They would not be restricted in using the isokinetic device. Subjects were performed knee flexion and extension at speed of 30 degree per sec, 60 degree per sec and 120 degree per sec. In training had about 18 sessions in 6 weeks and began by 5 minute warm up on stationary bicycle at low resistance flow by 15 second to stretch each for quadriceps and hamstring in affected side. After that, they were performed knee flexion and extension on isokinetics machine and worked maximal effort about 6 to 8 repetitions per set, 3 set per sessions. They found that, the paretic muscle strength improved after training while tone remained consistent. Gait velocity increased after training and at follow-up.

In 2003, Silva and co-workers (77) evaluated the knee strength after total knee arthroplasty by used a Lido Active Dynamometer. In this study, subjects were separated two groups, first group was control knee (no total knee arthroplasty), and second group was patient with total knee arthroplasty at least 2 years after surgery. The testing had 7 positions at 0 degree, 15 degree, 30 degree, 45 degree, 60 degree and 75 degree of isometric knee extension and flexion. Average isometric extension peak torque value in total knee arthroplasty was reduced by up to 36.7%. Relatively greater quadriceps strength was associated with a better functional score. Older total knee arthroplasty patients generated lower isometric extension peak torque value in terminal extension than younger total knee arthroplasty patients. Higher body mass index was associated with relative quadriceps weakness.

2.4 Energy profiles

The human body utilizes energy to support metabolic process such as muscle contraction and relaxation and for cellular reaction such as active transport systems, hormone receptor signaling, and protein synthesis. The fuel for the body' energy requirements comes from ingested nutrients or from stored glycogen and fat (71). People naturally walk in a manner that conserves energy. To accomplish this, limb and trunk motion are integrated to decrease the vertical displacement of the center of gravity. Walking speeds are selected to minimize the energy expended per distance walked. Deviation from the normal walking pattern and comfortable walking speed increases energy expenditure. The factor of energy expenditure during walking were speed in walking, age, weight and gender (71).

Metabolic energy cannot be measured directly as the amount of heat produced if a subject is walking. It can be indirectly calculated from the amount of oxygen required or the amount of carbon dioxide given off. Energy expenditure is measured by the rate of oxygen consumed as a function of walking speed. Energy efficiency measurements describe the relationship of mechanical output to metabolic energy and must include a measure of the work that was done (71).

Energy expenditure during walking is often measured by the amount of oxygen utilized by the body per unit time. The amount of oxygen in the inhaled air is compared with amount of oxygen in the exhaled air. One of the most accurate measurements of this ratio can be obtained with a fixed mixing chamber. The percent of oxygen in the exhaled air must be compared with a known percent of oxygen in the inhaled air. The subject inhales room air through a one-way valve and exhales into a mixing chamber. The analyzer continuously calculates the percentage of carbon dioxide and oxygen within the chamber breath-by-breath or minute-by-minute. The equipment is not portable, however, and measurements during walking require the subject to walk on a treadmill (71).

In the analysis of energy expenditure, the respiratory quotient (RQ), which is the ratio of carbon dioxide production to oxygen consumption at rest, relates to the type of food that is metabolized. Interpretation of the RQ rest on the assumption that analysis of air exchange in the lung is the same as gas exchange at the cellular level and reflects the oxidation of specific food sources. The RQ for a pure carbohydrate diet is 1.00. The RQ for a pure fat diet is 0.70. A typical mixed diet consisting of 60% metabolized fats and 40% metabolized carbohydrates results in a RQ of 0.82 at rest and the caloric equivalent is 4.8 cal per ml oxygen (71).The respiratory exchange ratio (RER) is calculated the same as the RQ , and this term is used under exercise condition. Sustained strenuous exercise resulting in a RER greater than 0.90 indicates anaerobic activity. A ratio greater than 1.00 indicates sever exercise. From a practical standpoint, the RER provides a convenient, noninvasive method of determining whether significant anaerobic metabolism is occurring (71).

Bhambhani and co-worker in 1997 (7) studied about the physiological and biomechanical response during treadmill walking with graded loads. The purpose of the study was to compare acute response during treadmill walking with 15-kilograms and 20- kilograms loads carried bilaterally by health males. By subjects bilateral carried 15-kg and 20-kg loads for 4 min and walked on treadmill at their self-selected velocity. They found significant increased in oxygen consumption, heart rate, cardiac output and mean blood pressure during both of the load carriable walks compared to unloaded walking. However, stroke volume, arterio-venous oxygen difference, rate pressure product and total peripheral resistance were unchanged during load carriage.

Their result suggested that increasing the load from unload to load carriage during walking on treadmill does significantly increase the cardiovascular stress.

Booyens and Keatinge in 1957 (11) studied about expenditure of energy by men and women walking. By the protocol in studied was subject walked along 600 yards and collected their expired air at 50 to 600 yards. It is believed that these measurements of energy expenditure will be within 5 percent of steady state and walked at two rate (leisurely one and to catch a bus). They found, women expend significantly less energy per unit body weight than men at both speeds. The smaller expenditures of energy of women were associated with their relatively short strides, and it is suggested that their lower expenditures were due to the smaller amount of work they perform in lifting the body vertically.

Brehm and co-worker in 2004 (12) studied to validate the accuracy of a new type of portable gas-analysis system (Sensormedics VmaxST). By each subject performed two trials in same day and randomization. Subject started with the VmaxST trial followed by the Douglas Bag trial and the other five started at the Douglas Bag trial followed by the VmaxST. Each trial consigned of 2 phase, the first phase was rested about 5 minute in a comfortable chair and the second phase was biked the cycling ergometer at 80 watt. The criterion method was the Douglas Bag method, which is considered to be the gold standard. The result shows that no significant difference was found between the VmaxST and the Douglas Bag method for the primary parameter. Therefore, the validity of VmaxST is sufficient for use in gait studies to determine the energy cost by walking.

Ebbeling and co-works in 1994 (25) studied the energy cost and lower extremity mechanics in shoes of difference heel heights (1.25, 3.81, 5.08, 7.62cm) in fifteen female subjects. They used force platform and gas analyzer to investigate. Heart rate and oxygen consumption were monitored while subjects walked on a treadmill at 4.2 km/hr. Metabolically, heart rate and oxygen consumption also increased with heel height. The value of energy cost was not significantly different at the three lower heel heights but increased significantly between these heights and the highest heel height.

Mathew and Wooten in 1963 (57) compared the oxygen consumption of ten women walking barefoot and in three popular shoe styles. They studied in female subjects, age between 24 to 40 years. The shoe styles were sandals, loafers, and high-heel. They used gas analyzer to investigate oxygen consumption, carbon dioxide output. By each subject walked on treadmill at 2 miles per hour for a period of 10 minute. Subject walked at least twice under each condition on the horizontal and on the 6 percent grade. They found no significant difference in oxygen consumption between sandals, loafers and barefoot walking. Whereas, high-heel shoes had a greater energy cost. The results were the similar for both walking on the horizontal and the six percent grade. There was no significant difference among means in the change of the position of center of gravity of the body as measured while wearing various types of shoes and while barefoot.

CHAPTER 3
MATERIALS AND METHODS

3.1 Subjects

Eight female students from College of Sports Science and Technology, Mahidol University age from 18 to 22 years, participated in this study. Each subject was explained about objective, method, risk and advantages of the study. Subjects were appraised about process and signed informed consent. Physical examination of every subject was performed by physical therapy.

All of subjects had the following inclusion criteria: They were inexperienced high-heel wearers. They could fit high-heel shoes between size 6 and 7. They were currently free of injury likely to affect their walking with high-heel shoes.

None of subjects had the following exclusion criteria: They had history of musculoskeletal problem (such as flat feet, genu vagus, genu varus) of either of both lower extremities in the past 6 months prior to the study. They had serious injury or operation history of either or both lower extremities. They had history of neuromuscular disorder. They had pain or some symptom disturbing testing**.**

3.2 Instrumentation

3.2.1. Isokinetics Machine [Lido Multi-Joint II, Loredan Biomedical,Inc., CA]

3.2.2. Isokinetics programs [Lido Multi-Joint II, Loredan Biomedical, Inc.,CA]

3.2.3. Treadmill [2000 Treadmill, SensorMedics, USA]

3.2.3. Oxygen analyzer [Vmax Series, SensorMedics, USA]

3.2.4 A force plate with 60x40x10 centimeters in size (AMTI) and AD converter control unit (AMTI)

3.2.5 Force analysis program (AMTI)

3.2.6 Heart rate monitor [Polar]

3.2.7 Goniometer

3.2.8 Measuring Tape

3.2.10 High-heel shoes size between 6 and 7 and heel height 3.8 cm., 5.08 cm., 6.35 cm. and 7.62 cm.

3.3 Experimental protocols

Before all things, subjects were asked to fill in a questionnaire about age, height, weight, size of shoes, and history of injury or musculoskeletal problems. The data were used to screen subjects before test. Subjects were informed to make understanding of purpose, method and advantage of the study. Subjects were explained about the process of the data collection. Then, subjects were asked to sign a consent form. All of testing trials were performed in the Biomechanics Laboratory at the College Sports Science and Technology, Mahidol University.

3.3.1 Subject preparation

Each subject was measured muscle strength (hip flexor, hip extensor, hip adductor, hip abductor, hip external rotator hip internal rotator, knee flexor, knee extensor, ankle dorsiflexor, ankle plantarflexor, ankle evertors and ankle inversor) and range of motion of hip joints, knee joints and ankle joints. Whereas, the leg lengths were measured from anterior superior iliac spine to medial malleolus. After that, subjects were tested footprint on 10 meter walkway and subject had five practice trail before foot print test, they walked at comfortable velocity. In test, subjects immersed their feet in color salver and walked on walkway. Tester controlled the stopwatch for computed the velocity of walking. In footprint could measure the stride length, step length, step width, foot width, foot length and velocity. Whereas, the cadence could be measured by subject walk around the laboratory at College of Sports Science and Technology. The stride length was measured from the distance between ground of one foot and the subsequent ground contact of the same foot. Step length was the distance between ground contact of one foot and the subsequent ground contact of the opposite foot. Whereas, step width was computed from the perpendicular distance between heel centers of two consecutive foot contacts and foot angle the line of foot forward progression. The velocity could be computed from the distance of walkway divide by time during walked on walkway. Whereas, the cadence could count number the step during walking in 1 minute. The data were corrected and used to compare for subjects. Subjects were randomized in to five conditions. The actual heel heights for the shoes were: c1-3.81 cm., c2- 5.08 cm., c3- 6.35 cm., c4 -7.62 cm. and c5- bare feet Then, subjects were asked to rest for 10 to 15 minutes until heart rate and respiratory rate go to resting state in the quiet room. The heart rate was recorded using polar HR monitor that was attached to the subject' chest. This is a telemetry-based system whereby electrical signals generate by the heart rate detect by the transmitter wear on the chest and display on a wrist watch receiver. Subjects were asked to perform trials to assess ground reaction force, peak torque hamstring, peak torque quadriceps, h/q ratio and oxygen consumption. Trails were randomized and were tested one condition per day. An example of a subject time line can be shown in Appendix I

3.4.2 Hamstring/Quadriceps ratio test

Although all shoes were commercially available, they were similar in construction with the exception of the heel height. Each subject sits on the seat of Lido Multi-Joint II. Subject sat in the knee extension/flexion sitting position. Isokinetics dynamometer was set up to perform knee flexion in accordance with the subject individual leg length. Femoral condyle was aligned with the actuator shaft rotator head. Subject was stabilized using straps to ensure isolation of the exercise. With the subject holding the handgrip, the initial position is 90 degrees of knee flexion and the initial moment extension. Subjects were allowed familiarization period of the task, emphasizing the importance of maximum effort during the test and encouraged during test to push as hard as they could (46). Subjects were measured pre-test and post-test per each condition and five per condition at 60 degree per sec. In post-tests were measured after walking at walkway. Peak torque values (Newton meters) of flexion (hamstrings) and extension (quadriceps) were recorded and then used to calculate the ratio of hamstring and quadriceps.

3.4.3 Energy profiles test

After each subject completed from peak torque hamstring, peak torque quadriceps and h/q ratio data collection. They were asked to walk on treadmill. Prepare the equipment for open-circuit method of measurement of oxygen consumption (V?O_2), carbon dioxide (V?CO_2), and respiratory exchange ratio (RER).

Subject wore a mask and breathed through a respiratory valve, with a nose clip. The subjects's oxygen consumption (V?O$_2$), carbon dioxide (V?CO$_2$), and respiratory exchange ratio (RER) at resting were measured. And then, each subject is stand on the side of platform and facing forward. The machine with 0% was adjusted to a speed of 4 km/hr (4,6,13,18). Each subject was instructed to hold the forward handrail with right hand, then step the right forward onto the center of belt and start walking. After gained balance and prepared posture (upright, not slumped), the subject let go off handrail, and maintained walking position on belt. The subjects's oxygen consumption, carbon dioxide production and respiratory exchange ratio in every minute were measured (4) and walked on treadmill around twenty minute. After that the subject was asked to step off the treadmill, grasp the handrail and step onto the side of the treadmill with left foot (15).

3.3.4 Ground reaction force test

After each subject completed from energy profiles data collection. They were asked to walk on walkway. The speed was collected at 4 miles per hour by metronome and stop watch. Walking velocity was computed by using a pair of timing sensors. The vertical ground reaction force was collected through a force platform (AMTI) (with a natural frequency of 450 Hz, 12-bit A/D converter and sampling rate of 4,000 Hz) using a DT VEE sample program. Subject completed successful trial each for heel height 3.81 cm, 5.08 cm, 6.35 cm and 7.62 cm. Successful trials were defined as the trial which subject walk with speed within 5 % of 4 miles per hours and had completed contact with the force plate. The ground reaction force was represented in voltage and computed by body weight in form of voltage and multiply by 100.

3.5 Statistics

All data are presented as mean±SEM. An analysis of variance (ANOVA) was used for comparing individual variable to investigate difference between pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm conditions. Turkey Post-Hoc test was applied to compare the mean values. A repeated measure ANOVA was applied to investigate difference between the mean value of minute 5th, minute10th, minute 15th and minute 20th in each condition. Data were presented in raw data. All the statistical tested were performed by using the SPSS for window versions 11 program. The level of significance for differences between groups or between times was set at $p<0.05$.

CHAPTER 4

RESULTS

4.1 The physical characteristics of subjects.

There were eight female subjects. They were recruited from College of Sports Science and Technology. The physical characteristics of subjects shown in Table 3, the average value of age, body height, body weight and body mass index were 20.38 ± 0.65 yrs, 160.38 ± 0.15 cm, 50.75 ± 3.16 kg, 19.77 ± 1.33 kg/m^2 , respectively

Table 3 Physical characteristic of subject

Variable	Mean ± SEM
Age (yrs)	20.38 ± 0.65
Height (cm)	160.38 ± 0.15
Weight (kg)	50.75 ± 3.16
BMI ($kg//m^2$)	19.77 ± 1.33

Values are means ± SEM of age, body height, body weight and body mass index of subjects.

4.2 Temporal-spatial gait characteristics

Means and standard error of mean of temporal-spatial gait characteristics are presented in Table 4

Table 4 Temporal-spatial characteristic of gait of subjects

Variable	Mean ± SEM
Right foot width (cm.)	8.69 ± 0.13
Left foot width (cm.)	8.69 ± 0.13
Right foot length (cm.)	23.56 ± 0.26
Left foot length (cm.)	23.60 ± 0.24
Right stride length (cm.)	126.14 ± 3.87
Left stride length (cm.)	125.85 ± 4.03
Right step length (cm.)	63.68 ± 1.72
Left step length (cm.)	62.44 ± 2.16
Right step width (cm.)	6.65 ± 0.50
Left step width (cm.)	6.34 ± 0.36
Velocity (m/sec)	1.10 ± 0.22
Cadence (step/min)	105.88 ± 1.96

Values are means ± SEM of right foot width, left foot width, right foot length, left foot length, right stride length, left stride length, right step length, left step length, right step width, left step width, velocity and cadence.

4.3 Ground reaction force

In this study have a three characteristic of force. The first force was vertical ground reaction force, it have three components. The first component occurred at loading response (Fz_1), the second component occurred during mid-stance (Fz_2) and during push off phase (Fz_3). The second force was medial-lateral ground reaction force. It have three forces, were the first peak of medial-lateral ground reaction force (Fy_1), the second peak of medial-lateral ground reaction force (Fy_2) and the third peak of medial lateral ground reaction force (Fy_3). The last force was anterior posterior ground reaction force. It have two characteristics of force occurred at heel strike (Fx_1) and push off (Fx_2).

The mean and standard error of mean of vertical ground reaction, medial-lateral ground reaction and anterior-posterior ground reaction force during barefeet and high-heel gait are presented in Table 5.

Table 5 Comparisons of vertical ground reaction, medial-lateral ground reaction force and anterior-posterior ground reaction force between barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm.

Variable	barefeet	Heel height				*p*-value
		3.81 cm.	5.08 cm.	6.35 cm.	7.62 cm.	
VGRF						
Fz_1	107.17 ± 4.35	111.01 ± 4.13	113.00 ± 2.20	114.77 ± 2.47	118.78 ± 3.02	0.181
Fz_2	73.99 ± 3.33	73.27 ± 2.30	67.47 ± 3.19	72.33 ± 3.11	67.60 ± 3.36	0.398
Fz_3	110.16 ± 3.17	117.35 ± 3.56	118.34 ± 3.42	103.34 ± 13.22	118.87 ± 2.75	0.398
M-L GRF						
Fy_1	-15.51 ± 1.51	-12.74 ± 1.98	-12.70 ± 1.91	-11.22 ± 2.58	-12.73 ± 1.83	0.660
Fy_2	17.80 ± 2.66	19.63 ± 3.02	23.93 ±2.78	21.00 ± 2.49	22.04 ± 2.15	0.547
Fy_3	16.18 ± 2.28	19.96 ± 2.10	16.80 ± 1.72	13.05 ± 1.89	14.91 ± 2.17	0.201
A-P GRF						
Fx_1	-77.70 ± 9.73	-70.36 ± 5.38	-81.29 ± 7.21	-91.32 ± 5.72	-87.81 ± 7.07	0.279
Fx_2	99.60 ± 6.05	93.13 ± 5.17	96.52 ± 6.00	92.84 ± 3.06	92.57 ± 4.06	0.851

Values are means ± SEM, normalized by body weight and presented in percent body weight, statistical comparison show were One way ANOVA. Significant value $p < 0.05$. Fz_1 = the first peak of vertical ground reaction force, Fz_2 = the vertical ground reaction force, Fz_3 = the second peak of vertical ground reaction force, Fy_1 = The first peak of medial-lateral ground reaction force, Fy_2 = the second peak of medial-lateral ground reaction force, Fy_3 = the third peak of medial-lateral ground reaction force, Fx_1= the braking force of anterior-posterior ground reaction force and Fx_2 = the propulsive force of anterior-posterior ground reaction force.

From the Table 5, the first peak of vertical ground reaction force (Fz_1) were increased when walking with high-heel shoes. By the heel height 7.62 cm. was a greatest and more than heel height 6.35 cm., heel height 5.08 cm., heel height 3.81 cm. and barefeet. But shown no significant difference. The comparison of the first peak of vertical ground reaction force between walking by barefeet and wore high heel shoes were shown in Figure 8.

During walking with high-heel shoe, the vertical ground reaction force (Fz_2) was decreased. By the heel height 5.08 cm. have a greatest decreasing. Whereas in the heel height 7.62 cm., heel height 6.35 cm and heel height 3.81 cm. were respectively decreased. The comparison of the vertical ground reaction force during walking between barefeet and wore high-heel shoes were presented in Figure 9.

For the second peak of vertical ground reaction force (Fz_3)increased with high-heel shoes. By the second peak of vertical ground reaction force of heel height 5.08 cm. have a greater more than heel height 7.62 cm., heel height 3.81 cm., heel height 6.35 cm. and barefeet, respectively. The comparison of the second peak of vertical ground reaction force between barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm. were demonstrated in Figure 10.

The first peak force of medial-lateral ground reaction force (Fy_1) was decreased during walking with high-heel shoes. By heel height 6.35 cm. was decreased more than heel height 7.62 cm., heel height 5.08 cm., and heel height 3.81 cm. Whereas the first peak of medial-lateral ground reaction of barefeet have a greater force. The comparison of the first peak of medial-lateral ground reaction force between barefeet and high-heel shoes were shown in Figure 11.

During walking with high-heel shoes, the second peak force of medial-lateral ground reaction force (Fy_2) of heel height 5.08 cm. have a greater than heel height 7.62 cm., heel height 3.81 cm. and heel height 5.35 cm., respectively. The comparison of the second peak force of medial-lateral ground reaction force during walking with barefeet, heel height 3.81 cm, heel height 5.08 cm, heel height 6.35 cm and heel height 7.62 cm. were demonstrated in Figure 12.

For braking force of anterior-posterior ground reaction force (Fx_1), the force were increased during walking with high-heel shoes. However, the force of barefeet has a greater than heel height 3.81 cm. and lesser than heel height 7.62 cm., heel height 6.35 cm. and heel height 5.08 cm. The comparison of braking force of anterior-posterior ground reaction during walking with barefeet and high-heel shoes were shown in Figure 14.

During walking with high-heel shoes, the propulsive force of anterior-posterior ground reaction force (Fx_2) were decreased. By the decreasing of heel height 6.35 cm. more than heel height 7.62 cm., heel height 3.81 cm. and heel height 5.08 cm., respectively. The comparison of the propulsive force of anterior-posterior ground reaction force between barefeet and high-heel gait were presented in Figure 15.

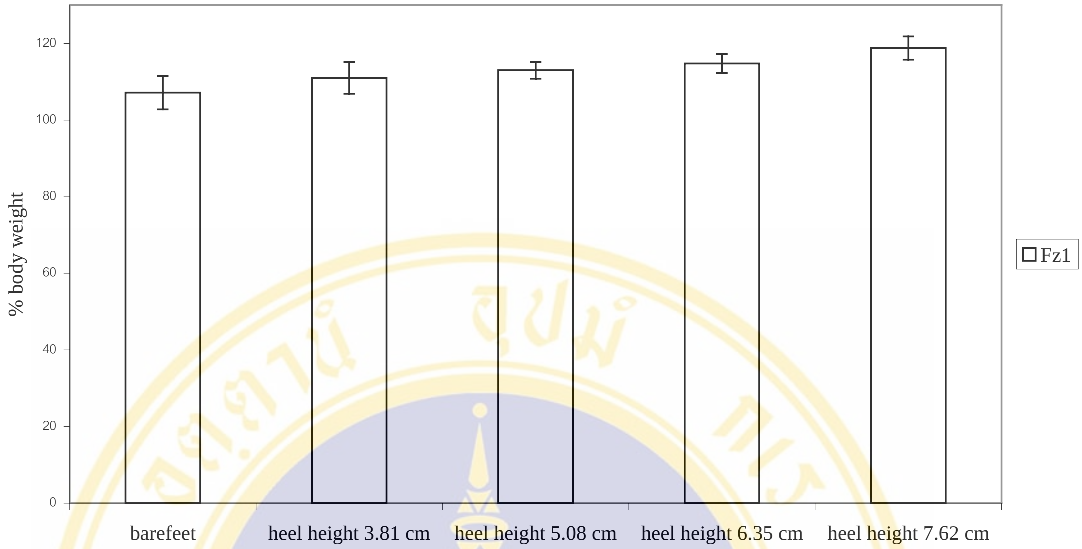

Figure 8 Comparison of the first peak of the vertical ground reaction between barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm. by mean ± SEM, normalized by body weight and presented in percent body weight, statistical comparison shown was One way ANOVA.

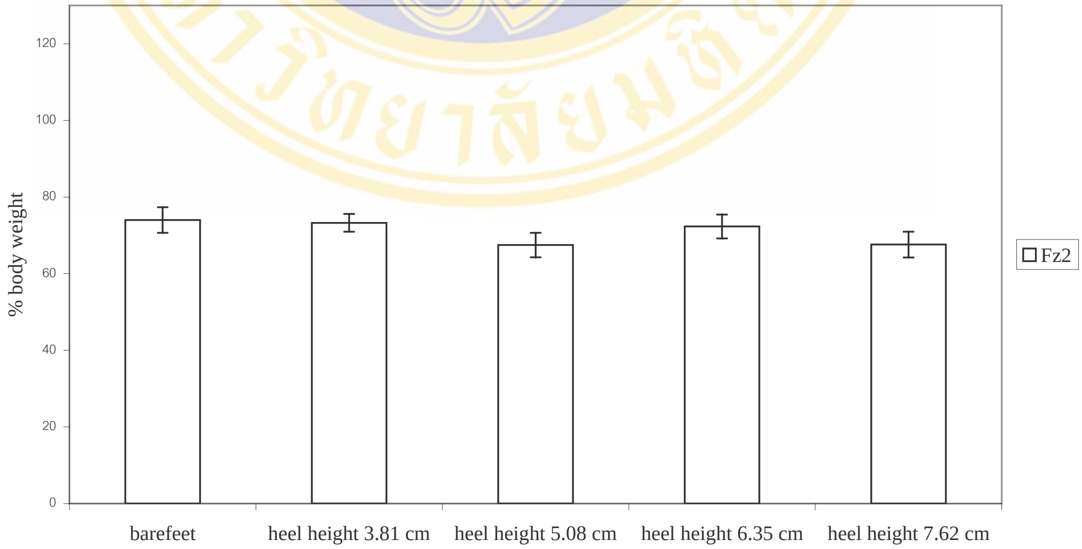

Figure 9 Comparison of the vertical ground reaction between barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm. by mean ± SEM, normalized by body weight and presented in percent body weight, statistical comparison shown was One way ANOVA.

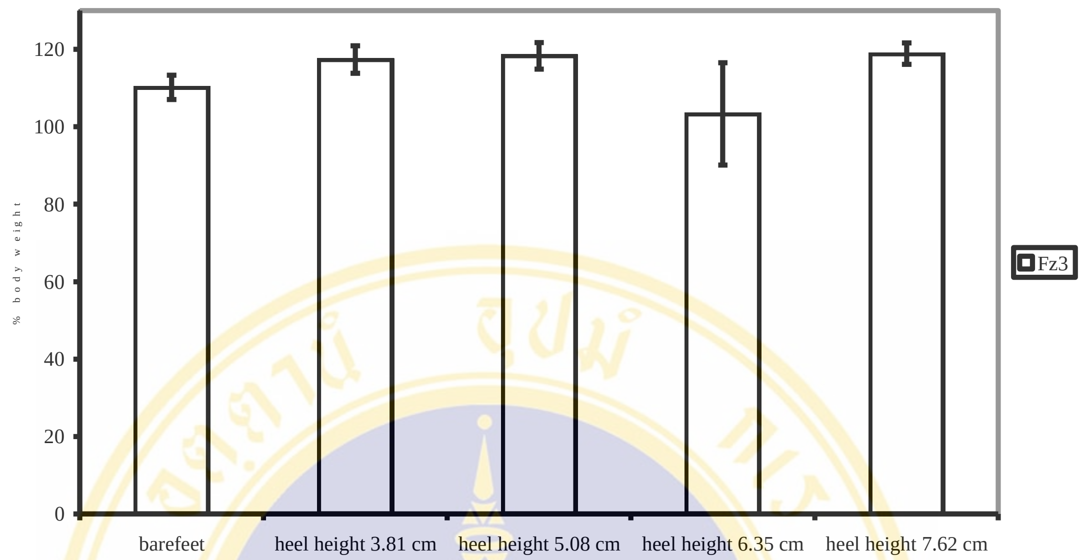

Figure 10 Comparison of the second peak of the vertical ground reaction between barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm. by mean ± SEM, normalized by body weight and presented in percent body weight, statistical comparison shown was One way ANOVA.

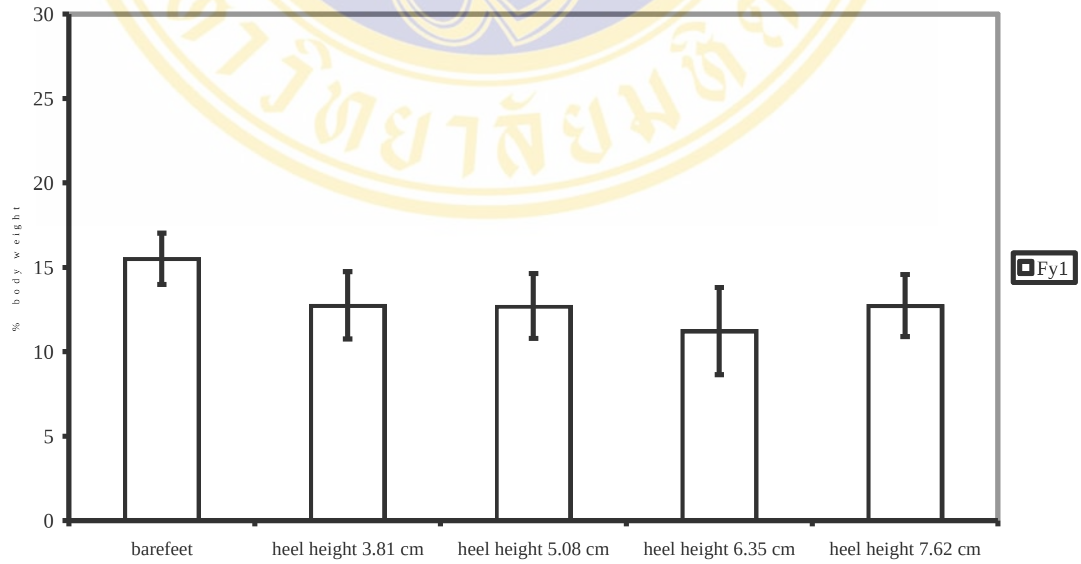

Figure 11 Comparison of the first peak of the medial-lateral ground reaction between barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm. by mean ± SEM, normalized by body weight and presented in percent body weight, statistical comparison shown was One way ANOVA

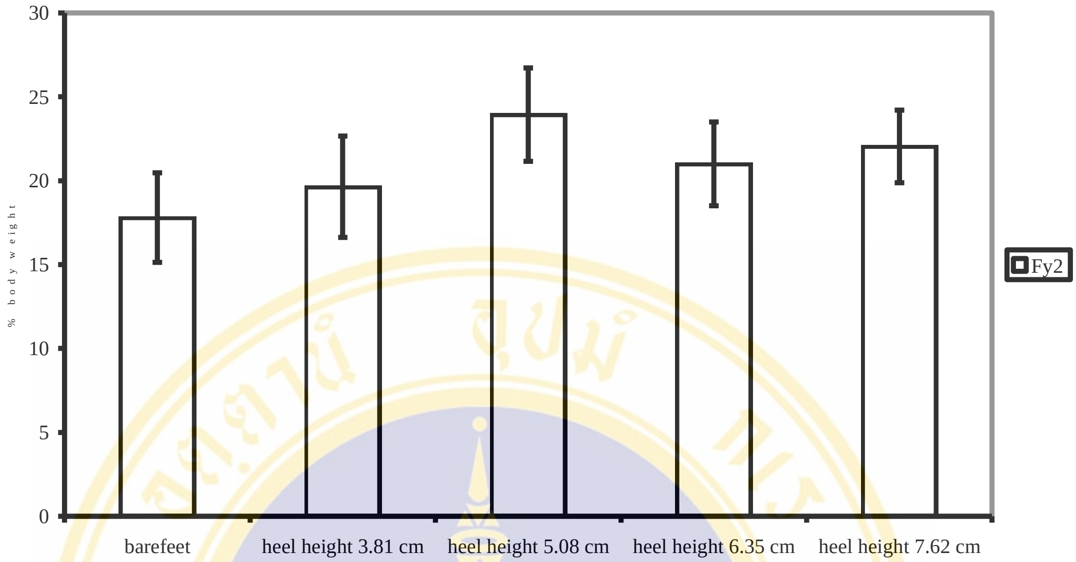

Figure 12 Comparison of the second peak of the medial-lateral ground reaction between barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm. by mean ± SEM, normalized by body weight and presented in percent body weight, statistical comparison shown was One way ANOVA

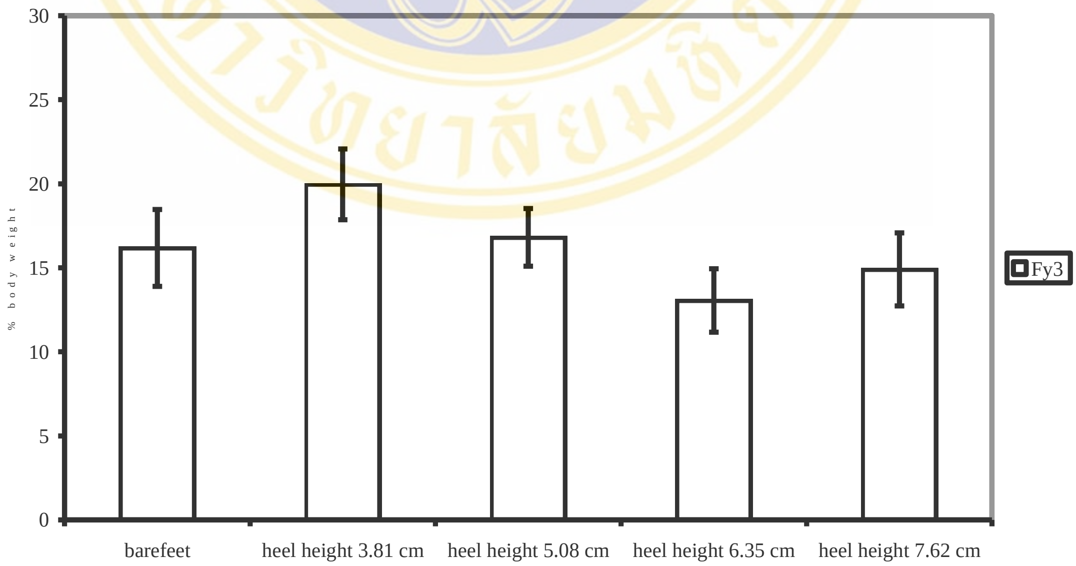

Figure 13 Comparison of the third peak of the medial-lateral ground reaction between barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm. by mean ± SEM, normalized by body weight and presented in percent body weight, statistical comparison shown was One way ANOVA

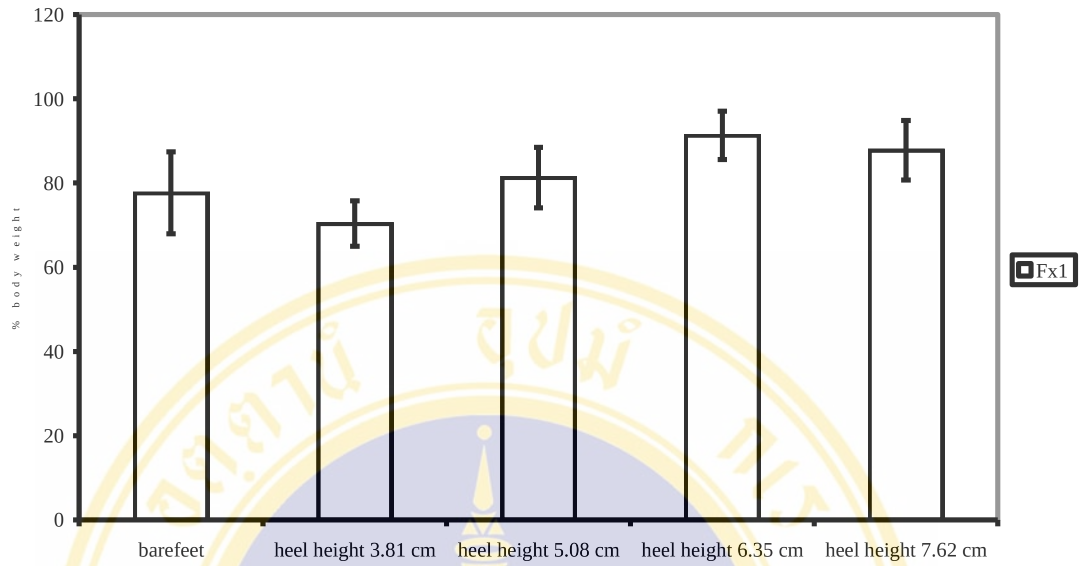

Figure 14 Comparison of the braking force of the anterior-posterior ground reaction between barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm. by mean ± SEM, normalized by body weight and presented in percent body weight, statistical comparison shown was One way ANOVA

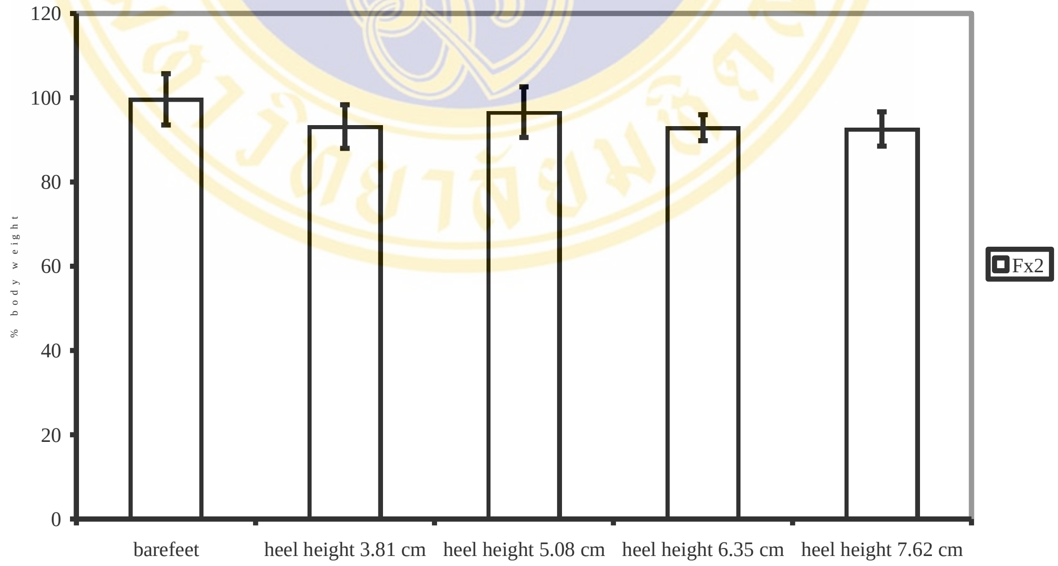

Figure 15 Comparison of the propulsive force of the anterior-posterior ground reaction between barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm. by mean ± SEM, normalized by body weight and presented in percent body weight, statistical comparison shown was One way ANOVA

4.4 Peak torque of hamstring, Peak torque of quadriceps and h/q ratio

The strength of subject was measured by isokinetics dynamometry. The peak torque of hamstring and the peak torque of quadriceps were the strength of hamstring and quadriceps muscles at 60 degree per sec. The last measurement was hamstring/quadriceps ratio (h/q ratio). It was the ratio of peak torque of hamstring and peak torque of quadriceps at 60 degree per sec, too. By measured before tested (pre-test), and after walked by barefeet and wore high-heel shoes. The value of the mean and standard error of means of peak torque of hamstring, peak torque of quadriceps and h/q ratio were presented in Table 6.

Table 6 Comparisons of peak torque of hamstring, peak torque of quadriceps and h/q ratio between pretest, bare feet, heel height 3.81 cm, heel height 5.08 cm, heel height 6.35 cm and heel height 7.62 cm.

Variable	Pre-test (Nm)	Barefeet (Nm)	Heel height (Nm)				*p*-value
			3.81 cm	5.08 cm	6.35 cm	7.62 cm	
Peak torque of hamstring	72.38 ± 5.11	64.50 ± 3.65	64.75 ± 3.12	58.63 ± 4.28	58.88 ± 5.07	53.38 ± 4.59	0.073
Peak torque of quadriceps	115.50 ± 6.45	106.00 ± 7.18	111.38 ± 7.17	101.38 ± 6.44	108.00 ± 7.20	100.13 ± 7.94	0.637
H/Q ratio	0.62 ±0.02	0.61 ±0.03	0.56 ±0.02	0.58 ±0.02	0.54 ±0.02	0.53 ±0.02	0.084

Values are means ± SEM, statistical comparison show were One way ANOVA. Significant value $p < 0.05$.

The peak torque of hamstring during barefeet, heel height 3.81 cm., heel height 5.08 cm, heel height 6.35 cm and heel height 7.62 cm. had lesser than pretest. However, the peak torque of hamstring during barefeet has more than heel height every condition. The comparison of the peak torque of hamstring between pretest, bare feet, heel height 3.81 cm., heel height 5.08., heel height 6.35., and heel height 7.62 cm were demonstrated in Figure 16.

In pretest, the peak torque of quadriceps had a greater than barefeet and high-heel gait. By the respective of peak torque of quadriceps was pretest, heel height 3.81 cm., heel height 6.35 cm., barefeet heel height 7.62 cm. and heel height 5.08 cm. The comparison of peak torque of quadriceps between pretest, barefeet and heel height condition were presented in Figure 17.

For the h/q ratio, the ratios were not difference. By the h/q ratio of pretest stilled more than barefeet and high-heel gaits. The comparison of h/q ratio between pretest, barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm. were shown in Figure 18.

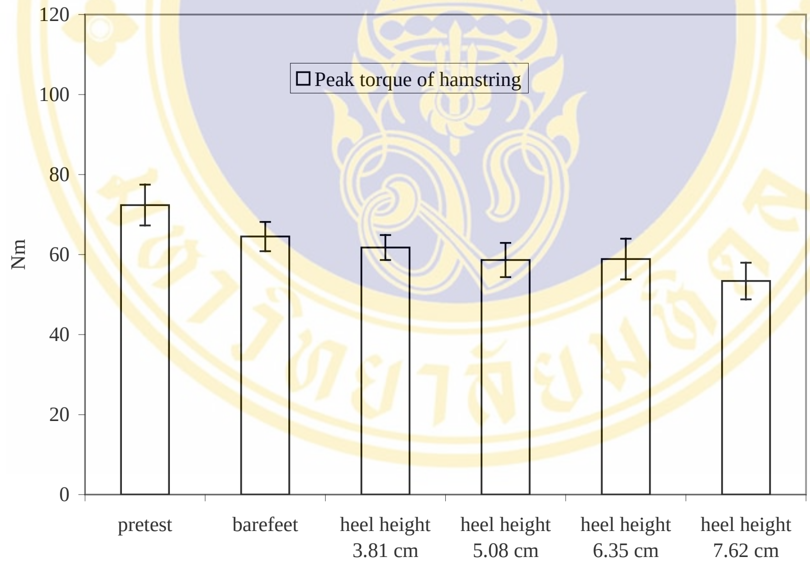

Figure 16 Comparisons of the peak torque of hamstring between pretest, barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm., and heel height 7.62 cm. by mean ± SEM, statistical comparison show was One way ANOVA. Significant value = $p < 0.05$.

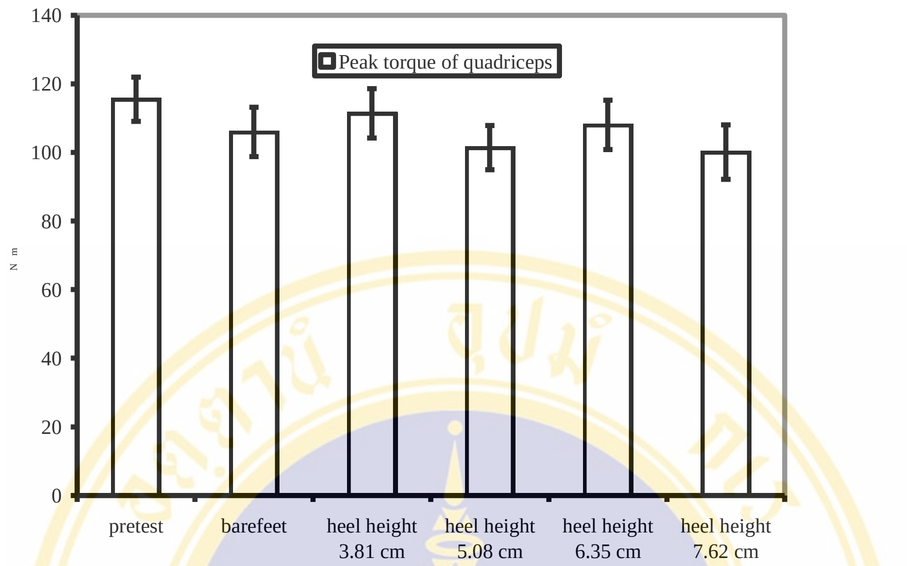

Figure 17 Comparisons of the peak torque of quadriceps between pretest, barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm., and heel height 7.62 cm. by mean ± SEM, statistical comparison show was One way ANOVA. Significant value = $p < 0.05$.

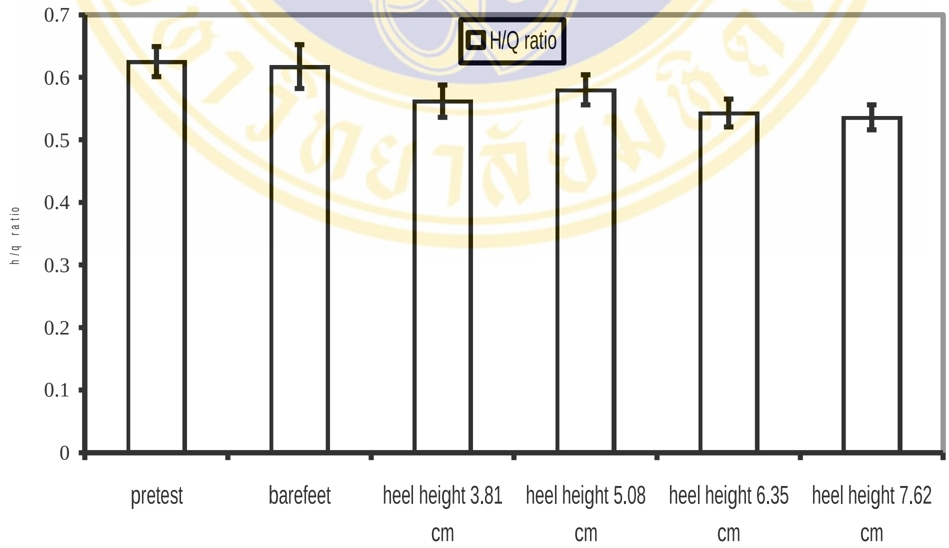

Figure 18 Comparisons of the hamstring/quadriceps ratio between pretest, barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm., and heel height 7.62 cm. by mean ± SEM, statistical comparison show was One way ANOVA. Significant value = $p < 0.05$.

4.5 The energy profile

The means and standard error of mean of heart rate, oxygen consumption, carbondioxide output, respiratory exchange ratio and minute ventilation were presented in Table 7-11

Table 7 Comparisons of the heart rate (Bpm) in minute 0, minute 5^{th}, minute 10^{th}, minute15^{th} and minute 20^{th} between pretest, barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm.and heel height 7.62 cm.

Variable	Pre-test	Bare feet	Heel height				*p*-value
			3.81 cm	5.08 cm	6.35 cm	7.62 cm	
HR 0	73.38 ±2.97	76.00 ±3.04	78.00 ±3.15	77.00 ±2.78	79.13 ±2.59	78.63 ±3.38	0.777
HR 5^{th}	79.50 ±3.61	98.38 $\pm2.91^{A}$	104.63 $\pm4.23^{A}$	106.25 $\pm4.68^{A}$	108.50 $\pm3.34^{A}$	111.25 $\pm3.97^{A}$	0.000
HR 10^{th}	82.13 ±2.86	102.00 $\pm3.24^{A}$	106.80 $\pm4.55^{A}$	107.75 $\pm4.97^{A}$	110.50 $\pm3.79^{A}$	111.13 $\pm3.62^{A}$	0.000
HR 15^{th}	82.25 ±2.72	102.25 $\pm3.24^{A}$	108.38 $\pm .55^{A}$	109.63 $\pm4.97^{A}$	113.88 $\pm3.76^{A}$	115.38 $\pm3.63^{A}$	0.000
HR 20^{th}	82.63 ±3.7	103.38 $\pm3.16^{A}$	108.75 $\pm3.98^{A}$	111.75 $\pm5.03^{A}$	114.50 $\pm4.04^{A}$	116.13 $\pm3.62^{A}$	0.000

Values are means ± SEM, statistical comparison show were One way ANOVA. Significant value $p < 0.05$. HR = heart rate, 0 = minute 0, 5^{th} = minute 5^{th}, 10^{th} = minute 10^{th}, 15^{th} = minute 15^{th} and 20^{th} = minute 20^{th}. ^{A} = Significant difference from pretest, $p < 0.00$.

Table 8 Comparisons of oxygen consumption (ml/kg/min) in minute 0, minute 5th, minute 10th, minute15th and minute 20th between pretest, barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm.and heel height 7.62 cm.

Variable	Pre-test	bare feet	Heel height				*p*-value
			3.81 cm	5.08 cm	6.35 cm	7.62 cm	
O_2 0	4.915 ±0.488	6.035 ±0.640	5.790 ±0.542	6.231 ±0.646	5.701 ±0.528	6.021 ±0.455	0.624
O_2 5th	6.076 ±0.541	13.414 $\pm0.681^A$	13.143 $\pm0.326^A$	14.013 $\pm0.405^A$	15.378 $\pm0.678^A$	14.895 $\pm0.621^A$	0.000
O_2 10th	5.395 ±0.402	12.732 $\pm0.294^A$	13.529 $\pm0.471^A$	14.616 $\pm0.748^A$	13.735 $\pm 0.517^A$	14.661 $\pm0.742^A$	0.000
O_2 15th	5.462 ±0.288	13.117 $\pm0.516^A$	14.630 $\pm1.540^A$	14.528 $\pm1.012^A$	14.271 $\pm0.440^A$	14.572 $\pm0.901^A$	0.000
O_2 20th	5.569 ±0.305	12.234 $\pm0.426^A$	14.052 $\pm0.889^A$	14.007 $\pm0.887^A$	14.902 $\pm0.742^A$	14.800 $\pm0.825^A$	0.000

Values are means ± SEM, statistical comparison show were One way ANOVA. Significant value $p < 0.05$. O_2 = oxygen consumption, 0 = minute 0, 5th = minute 5th, 10th = minute 10th, 15th = minute 15th and 20th = minute 20th. ^{A} = Significant difference from pretest, $p < 0.00$.

Table 9 Comparisons of the carbon dioxide output(ml/kg/min) in minute 0, minute 5th, minute 10th, minute15th and minute 20th between pretest, barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm.and heel height 7.62 cm.

Variable	Pre-test	bare feet	Heel height				*p*-value
			3.81 cm	5.08 cm	6.35 cm	7.62 cm	
CO_2 0	4.464 ± 0.479	5.125 ± 0.445	5.034 ± 0.382	5.692 ± 0.608	5.220 ± 0.434	5.478 ± 0.315	0.511
CO_2 5th	5.598 ± 3.400	13.003 ± 0.482^A	12.534 ± 0.351^A	13.547 ± 0.369^A	14.643 ± 0.706^A	14.262 ± 0.700^A	0.000
CO_2 10th	5.540 ± 0.444	13.019 ± 0.367^A	13.760 ± 0.386^A	14.826 ± 0.513^A	13.923 ± 0.596^A	15.093 ± 0.687^A	0.000
CO_2 15th	5.477 ± 0.270	13.838 ± 0.601^A	14.889 ± 1.429^A	14.973 ± 0.963^A	14.791 ± 0.584^A	14.870 ± 0.898^A	0.000
CO_2 20th	5.694 ± 0.353	12.675 ± 0.533^A	14.410 ± 0.972^A	14.585 ± 0.846^A	15.363 ± 0.786^A	15.196 ± 0.784^A	0.000

Values are means ± SEM, statistical comparison show were One way ANOVA. Significant value $p < 0.05$. CO_2 = carbon dioxide output, 0 = minute 0, 5th = minute 5th, 10th = minute 10th, 15th = minute 15th and 20th = minute 20th. ^{A} = Significant difference from pretest, $p < 0.00$.

Table 10 Comparisons of the respiratory exchange ratio(RER) in minute 0, minute 5th, minute 10th, minute15th and minute 20th between pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm

Variable	Pre-test	Bare feet	Heel height				*p*-value
			3.81 cm	5.08 cm	6.35 cm	7.62 cm	
RER 0	0.915 ± 0.059	0.866 ± 0.051	0.884 ± 0.051	0.915 ± 0.056	0.930 ± 0.061	0.928 ± 0.054	0.954
RER 5th	0.941 ± 0.045	0.974 ± 0.021	0.954 ± 0.017	0.970 ± 0.030	0.953 ± 0.023	0.957 ± 0.023	0.966
RER 10th	1.034 ± 0.067	1.023 ± 0.023	1.020 ± 0.017	1.021 ± 0.022	1.015 ± 0.027	1.032 ± 0.019	0.998
RER 15th	1.008 ± 0.034	1.056 ± 0.027	1.023 ± 0.016	1.035 ± 0.030	1.035 ± 0.022	1.022 ± 0.013	0.824
RER 20th	1.025 ± 0.046	1.035 ± 0.023	1.025 ± 0.019	1.047 ± 0.033	1.031 ± 0.019	1.029 ± 0.021	0.995

Values are means ± SEM, statistical comparison show were One way ANOVA. Significant value $p < 0.05$. RER = respiratory exchange ratio, 0 = minute 0, 5th = minute 5th, 10th = minute 10th, 15th = minute 15th and 20th = minute 20th.

Table 11 Comparisons of the minute ventilation (ml/kg/min) in minute 0, minute 5th, minute 10th, minute15th and minute 20th between pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm

Variable	Pre-test	bare feet	Heel height				*p*-value
			3.81 cm	5.08 cm	6.35 cm	7.62 cm	
V?E 0	11.213 ± 1.184	11.825 ± 1.364	11.825 ± 1.544	12.788 ± 1.622	12.338 ± 1.580	12.513 ± 1.471	0.978
V?E 5th	12.925 ± 1.729	21.538 ± 1.322	21.863 ± 1.396^{A}	22.063 ± 2.325^{A}	24.163 ± 2.942^{A}	22.100 ± 2.436^{A}	0.010
V?E 10th	13.625 ± 1.573	22.296 ± 1.546	23.038 ± 2.210^{A}	23.538 ± 2.095^{A}	22.600 ± 2.794	24.262 ± 2.587^{A}	0.014
V?E 15th	13.113 ± 1.672	23.850 ± 1.670^{A}	24.800 ± 1.832^{A}	25.388 ± 2.474^{A}	24.913 ± 3.041^{A}	22.713 ± 2.531^{A}	0.003
V?E 20th	13.800 ± 1.667	22.738 ± 2.015	14.338 ± 2.145^{A}	25.138 ± 2.469^{A}	25.688 ± 3.148^{A}	24.525 ± 2.651^{A}	0.010

Values are means ± SEM, statistical comparison show were One way ANOVA. Significant value $p < 0.05$. V?E = minute ventilation, 0 = minute 0, 5th = minute 5th, 10th = minute 10th, 15th = minute 15th and 20th = minute 20th. ^{A} = Significant difference from pretest, $p < 0.01$ at minute5th, $p < 0.014$ at minute 10th , $p < 0.003$ at minute 15th and $p < 0.01$ at minute 20th .

During tested, the heart rate were increased, respectively. At minute 0, the heart rate in each condition had no significant difference (p<0.05) and the heart rate of pretest at minute 5th, minute10th, minute 15th and minute 20th shown significant differences from barefeet and high-heel gait (p<0.05). Whereas, the heart rate at minute 5th, minute10th, minute 15th and minute 20th between barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. And heel height 7.62 cm. shown no significant difference (p<0.05) but the heart rate of heel height 7.62 cm. have a greater than heel height 6.35 cm, heel height 5.08 cm, heel height 3.81 cm and barefeet, respectively. The comparison of heart rate in minute 0, minute 5th, minute 10th, minute

15th and minute 20th between pretest, bare feet and high-heel gait are shown in Figure 19. Whereas, the comparison of heart rate between minute 0, minute 5th, minute 10th, minute 15th and minute 20th in each condition, by pretest condition, the heart rate at minute 5th, minute 10th, minute 15th and minute 20th shown significant difference from minute 0 (p<0.05) and the heart rate in minute 20th had significant difference from minute 5th (p<0.05). However, the heart rate in pretest condition had a little change. For bare feet condition, the heart rate had slowly increased. By the heart rate in minute 5th , minute 10th , minute 15th and minute 20th shown increased significant difference from minute 0 (p<0.05). Whereas the heart rate in minute 10th , minute 15th and minute 20th shown increased significant difference from minute 5th (p<0.05). In heel height 3.81 cm., the heart rate in minute 5th , minute 10th , minute 15th and minute 20th shown increased significant difference from minute 0 (p<0.05). and the heart rate in minute 10th and minute 20th shown significant difference from minute 5th (p<0.05). Whereas in heel height 5.08 cm condition, the heart rate in minute 5th , minute 10th , minute 15th and minute 20th shown increased significant difference from minute 0 (p<0.05). and the heart rate in minute 20th had increased significant difference from minute 5th and minute 10th (p<0.05). In heel height 6.35 cm condition, the heart rate in minute 5th , minute 10th , minute 15th and minute 20th shown increased significant difference from minute 0 (p<0.05) and the heart rate in minute 15th and minute 20th shown significant difference from minute 5th and minute 10th (p<0.05). Whereas in heel height 7.62 cm, the heart rate in minute 5th , minute 10th , minute 15th and minute 20th shown increased significant difference from minute 0 (p<0.05). The heart rate in minute 15th had significant difference from minute 10th (p<0.05), whereas the heart rate in minute 20th shown significant difference from minute 5th and minute 10th (p<0.05). The comparison of heart rate between minute 0, minute 5th, minute 10th , minute 15th and minute 20th in each condition were demonstrated in Figure 20.

The oxygen consumption in every condition at minute 0 had no significant difference from each other (p<0.05). The oxygen consumption were increased at minute 5th and kept at minute 10th, minute 15th and minute 20th. Whereas the oxygen consumption of bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm in minute 5th ,minute 10th , minute 15th and minute 20th had increased significant difference from pretest (p<0.05). But the oxygen consumption in minute 5th, minute 10th , minute 15th and minute 20th between bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm shown no significant difference (p<0.05). The comparison of the oxygen consumption in minute 0, minute 5th, minute 10th, minute 15th and minute 20th between pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm were presented in Figure 21. The comparison of the oxygen consumption between minute 0, minute 5th, minute 10th , minute 15th and minute 20th in pretest condition had no significant difference (p<0.05). Where as in bare feet and heel height condition the oxygen consumption at minute5th, minute 10th , minute 15th and minute 20th had increased significant difference from minute 0 (p<0.05). And the oxygen consumption between minute5th, minute 10th, minute 15th and minute 20th in bare feet and heel height condition shown no significant difference (p<0.05) but the oxygen consumption in minute10th from heel height 6.35 cm. had significant difference from minute 5th (p<0.05). The comparison of oxygen consumption between minute 0, minute5th, minute 10th, minute 15th and minute 20th in pretest, bare feet and heel height condition were presented in Figure 22.

The comparison of carbon dioxide output between pretest, bare feet and heel height condition, the carbondioxide output in minute 0 had no significant difference between pretest, bare feet and heel height condition (p<0.05). Whereas the carbon dioxide output in minute5th, minute 10th, minute 15th and minute 20th in bare feet and heel height condition showed significant difference from pretest condition (p<0.05). The comparison of carbon dioxide output between pretest, bare feet and heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm. condition were presented in Figure 23. Whereas, the comparison of carbon dioxide output between minute 0, minute5th, minute 10th, minute 15th and minute 20th in each condition had significant difference. By pretest condition, the carbon dioxide output in minute 15th had significant difference from minute 10th (p<0.05) . Whereas in bare feet and heel height condition, the carbon dioxide output in minute5th, minute 10th, minute 15th and minute 20th had significant difference from minute 0 (p<0.05). However the carbon dioxide output of heel height 3.81 cm. and heel height 5.08 cm in minute 10th shown significant difference from minute5th (p<0.05). The comparison of carbon dioxide output between minute 0, minute5th, minute 10th, minute 15th and minute 20th in pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm. were demonstrated in Figure 24.

The respiratory exchange ratio (RER) of pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm had no significant difference (p<0.05). By the comparison of , the respiratory exchange ratio between pretest, barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm were shown in Figure 25. Whereas, the comparison of respiratory exchange ratio between minute 0, minute5th, minute 10th, minute 15th and minute 20th in each condition had significant difference (p<0.05). By in barefeet and heel height 3.81 cm condition, the respiratory exchange ratio in minute 10th, minute 15th and minute 20th had significant difference from minute 0 and minute5th (p<0.05). In heel height 5.08 cm., the respiratory exchange ratio in minute 10th, minute 15th and minute 20th had significant difference from minute5th (p<0.05). Whereas, heel height 6.35 cm. condition, the respiratory exchange ratio in minute 15th and minute 20th shown significant difference from minute 10th (p<0.05). In heel height 7.61 cm., the respiratory exchange ratio in minute 10th, minute 15th and minute 20th had significant difference from minute5th (p<0.05). The comparison of respiratory exchange ratio between minute 0, minute5th, minute 10th, minute 15th and minute 20th in each condition were presented in Figure 26.

The minute ventilation at minute 0 had no significant difference between pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm (p<0.05). The minute ventilation at minute5th of height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm shown significant difference from pretest (p<0.05). At minute 10th, the minute ventilation of heel height 3.81 cm, heel height 5.08 cm. and heel height 7.62 cm had significant difference from pretest (p<0.05). Whereas in minute 15th the minute ventilation of barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm shown significant difference from pretest (p<0.05). However, the minute ventilation at minute 20th of barefeet and heel height condition had significant difference from pretest (p<0.05). The comparison of minute ventilation at minute 0, minute5th, minute 10th, minute 15th and minute 20th between pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm were shown in Figure

27. However, the comparison of the minute ventilation between minute 0, minute5th, minute 10th, minute 15th and minute 20th had significant difference (p<0.05). By in pretest condition, the minute ventilation at minute 20th had significant difference from minute 0 (p<0.05). Whereas in bare feet and heel height condition, the minute ventilation at minute5th, minute 10th, minute 15th and minute 20th shown significant difference from minute 0 (p<0.05). In heel height 3.81 cm., the minute ventilation at minute 15th had significant difference from minute 5th (p<0.05) and in heel height 7.62 cm., the minute ventilation at minute 20th had significant difference from minute 5th (p<0.05). The comparison of the minute ventilation between minute 0, minute5th, minute 10th, minute 15th and minute 20th in pretest, barefeet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm were demonstrated in Figure 28.

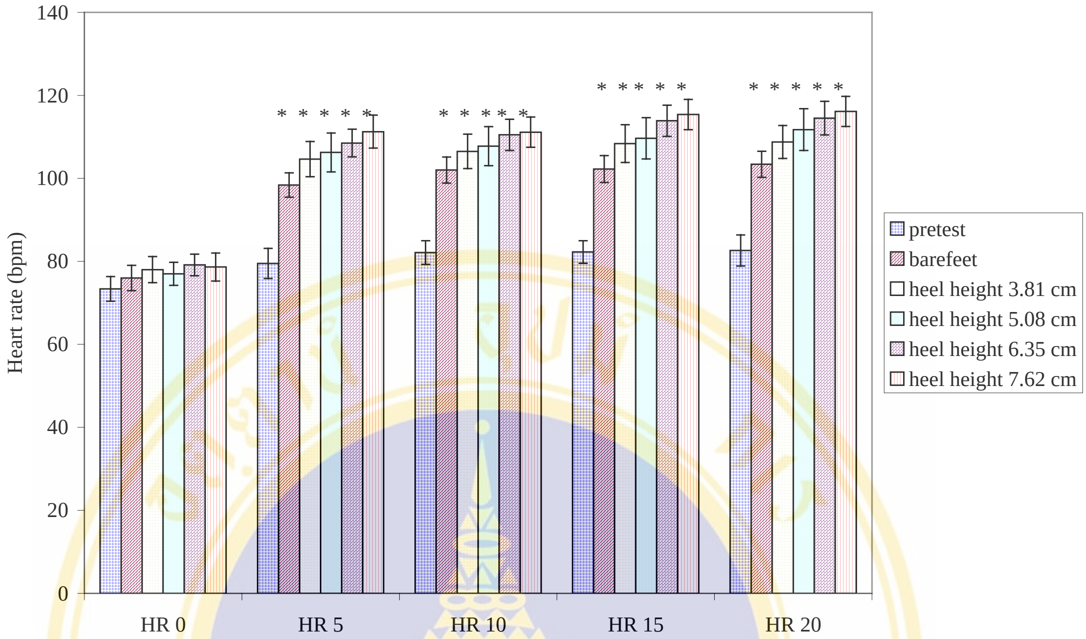

Figure 19 Comparison of the heart rate in minute 0, minute5th, minute 10th, minute 15th and minute 20th between pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm presented by mean ± SEM, statistical comparison shown were One way ANOVA. Significant value $p < 0.05$. HR 0 = heart rate at minute 0, HR 5 = heart rate at minute5th , HR 10 = heart rate at minute10th, HR 15= heart rate at minute15th and HR 20 = heart rate at minute 20th. * = significant difference from pretest.

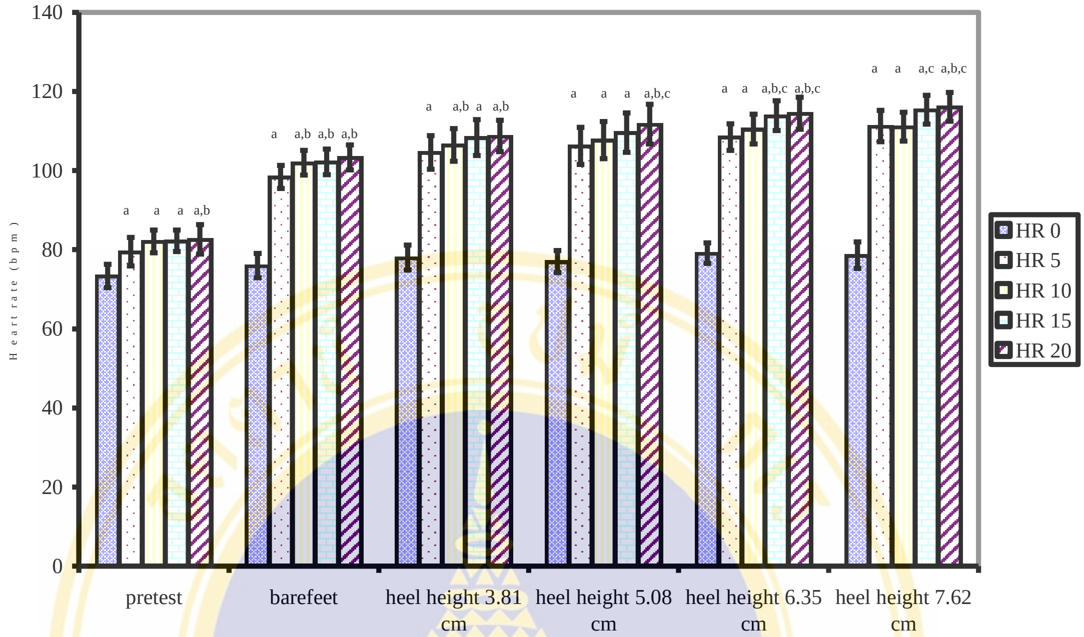

Figure 20 Comparison of the heart rate in pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm between minute 0, minute5th, minute 10th, minute 15th and minute 20th presented by mean ± SEM, statistical comparison shown were Repeated measure. Significant value $p < 0.05$. HR 0 = heart rate at minute 0, HR 5 = heart rate at minute5^{th,} HR 10 = heart rate at minute10th, HR 15= heart rate at minute15th and HR 20 = heart rate at minute 20th. a = significant from minute 0, b = significant from minute5th,c = significant from minute10th.

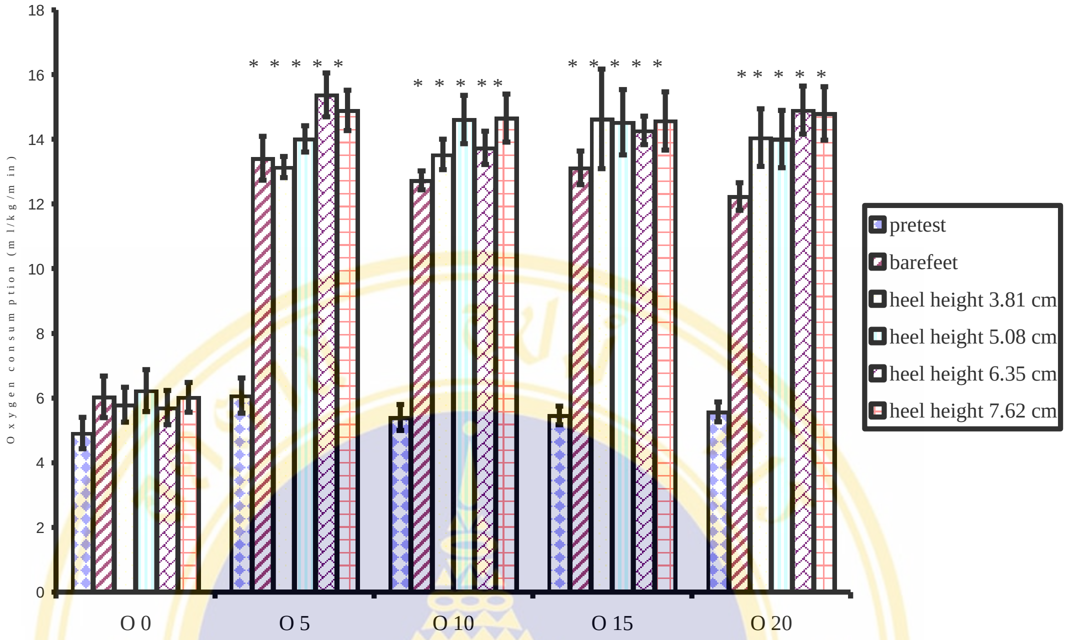

Figure 21 Comparison of the oxygen consumption in minute 0, minute5th, minute 10th, minute 15th and minute 20th between pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm presented by mean ± SEM, statistical comparison shown were One way ANOVA. Significant value $p < 0.05$. O 0 = oxygen consumption at minute 0, O 5 = oxygen consumption at minute5th, O 10 = oxygen consumption at minute10th, O 15= oxygen consumption at minute15th and O 20 = oxygen consumption at minute 20th. * = significant from pretest

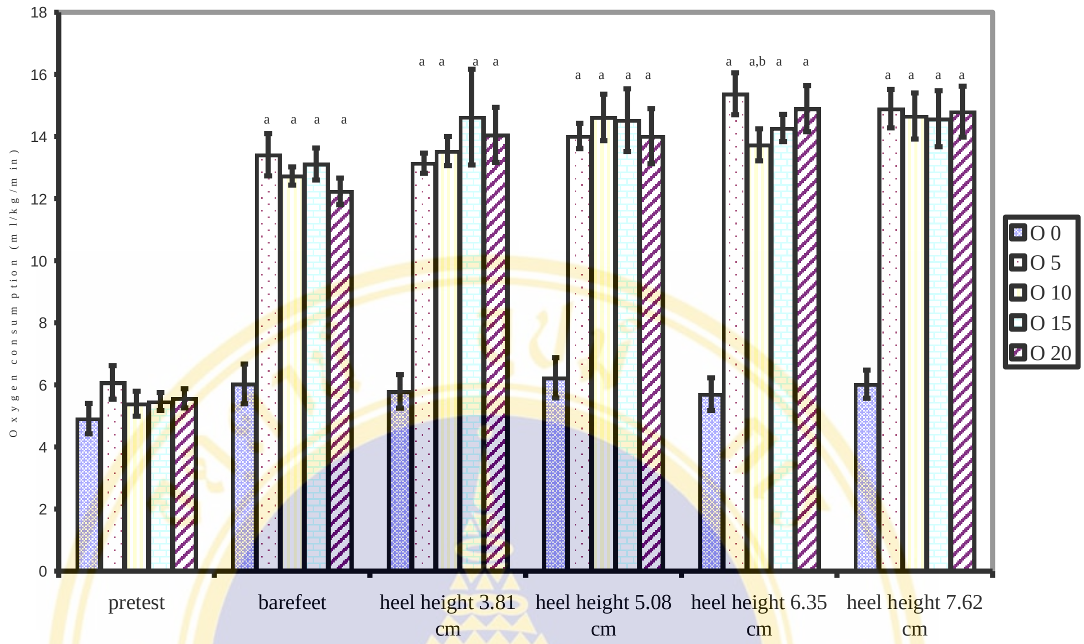

Figure 22 Comparison of the oxygen consumption in pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm between minute 0, minute5th, minute 10th, minute 15th and minute 20th presented by mean ± SEM, statistical comparison shown were Repeated measure. Significant value $p < 0.05$. O 0 = oxygen consumption at minute 0, O 5 = oxygen consumption at minute5th, O 10 = oxygen consumption at minute10th, O 15= oxygen consumption at minute15th and O 20 = oxygen consumption at minute 20th. a = significant from minute 0, b = significant from minute5th,c = significant from minute10th.

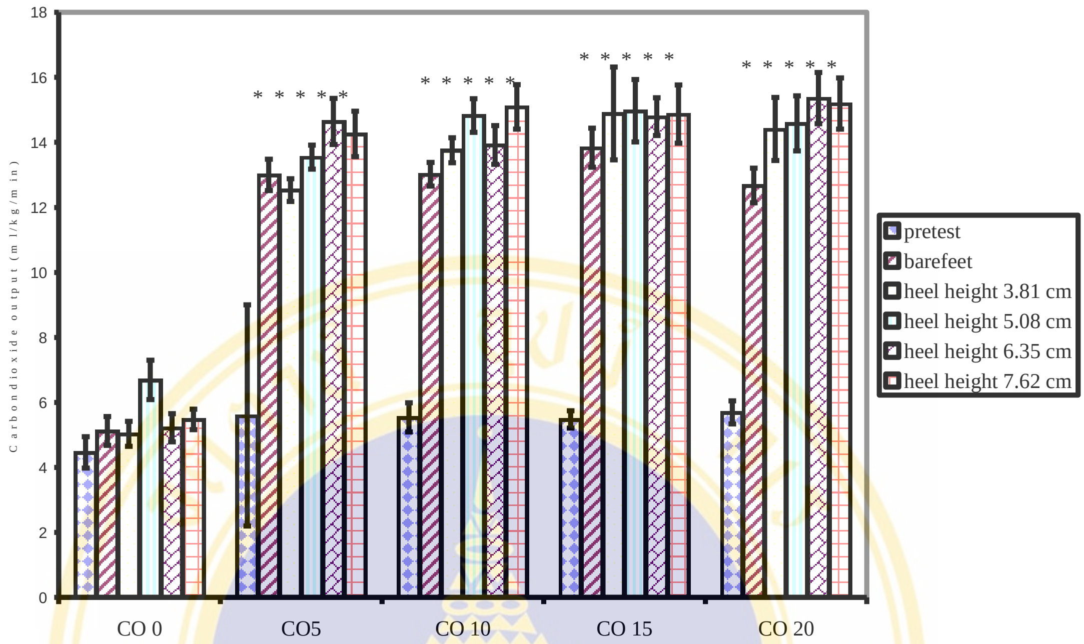

Figure 23 Comparison of the carbon dioxide output in minute 0, minute5th, minute 10th, minute 15th and minute 20th between pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm presented by mean ± SEM, statistical comparison shown were One way ANOVA. Significant value $p < 0.05$. CO 0 = carbondioxide output at minute 0, CO 5 = carbondioxide output at minute5th , CO 10 = carbondioxide output at minute10th, CO 15= carbondioxide output at minute15th and CO 20 = carbondioxide output at minute 20th. * = significant from pretest.

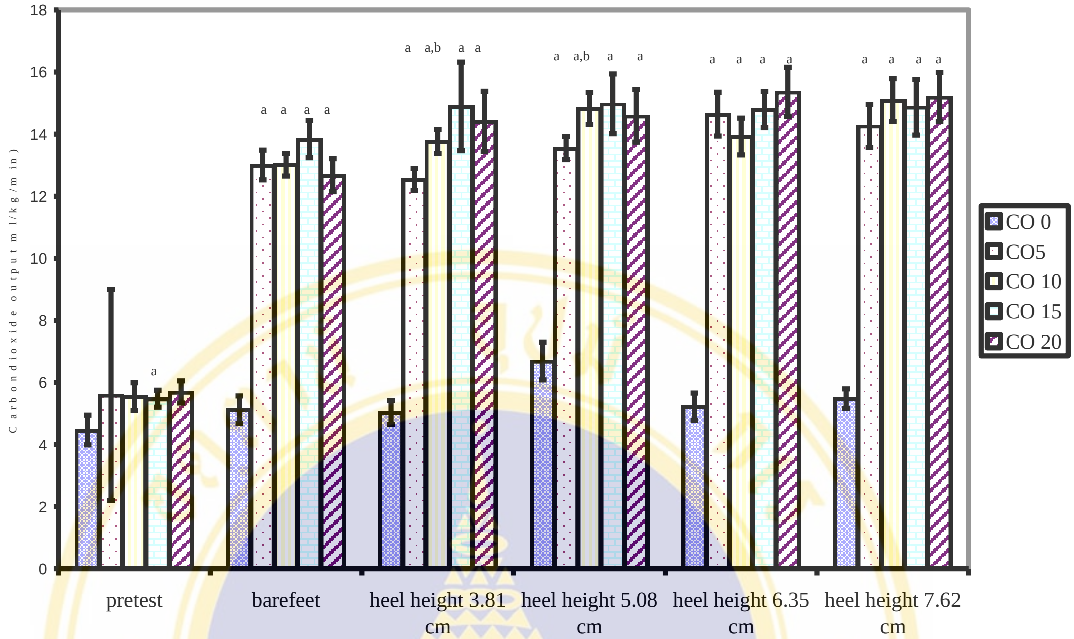

Figure 24 Comparison of the carbon dioxide output in pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm between minute 0, minute5th, minute 10th, minute 15th and minute 20th presented by mean ± SEM, statistical comparison shown were Repeated measure. Significant value $p < 0.05$. CO 0 = carbondioxide output at minute 0, CO 5 = carbondioxide output at minute5th , CO 10 = carbondioxide output at minute10th, CO 15= carbondioxide output at minute15th and CO 20 = carbondioxide output at minute 20th. a = significant from minute 0, b = significant from minute5th,c = significant from minute10th.

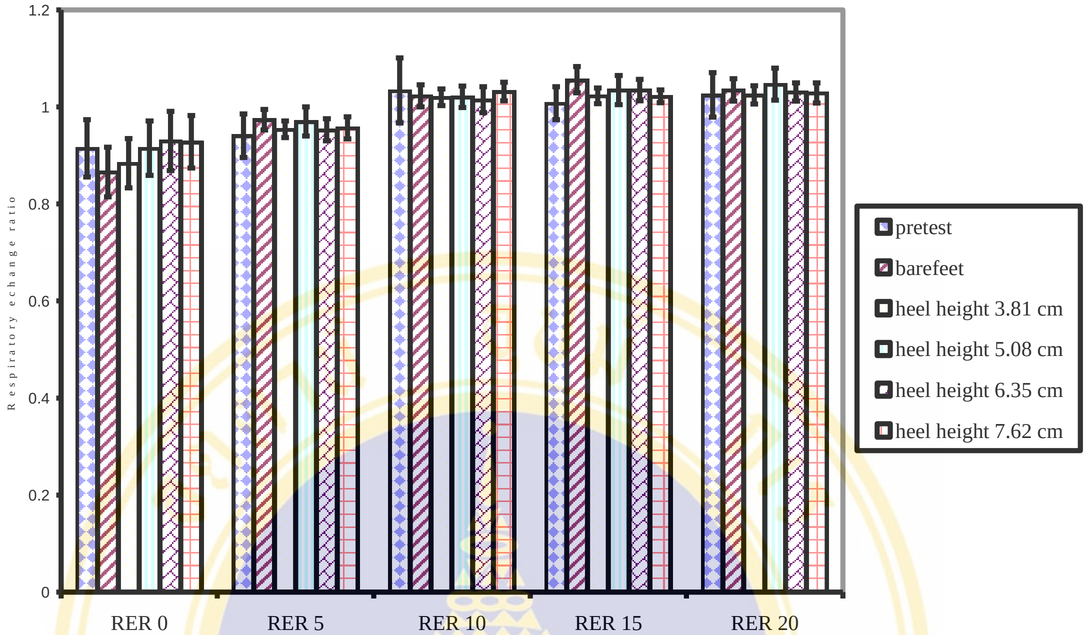

Figure 25 Comparison of the respiratory exchange ratio in minute 0, minute5th, minute 10th, minute 15th and minute 20th between pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm presented by mean ± SEM, statistical comparison shown were One way ANOVA. Significant value $p < 0.05$. RER 0 = respiratory exchange ratio at minute 0, RER 5 = respiratory exchange ratio at minute5th, RER 10 = respiratory exchange ratio at minute10th, RER 15= at minute15th and RER 20 = respiratory exchange ratio at minute 20th.

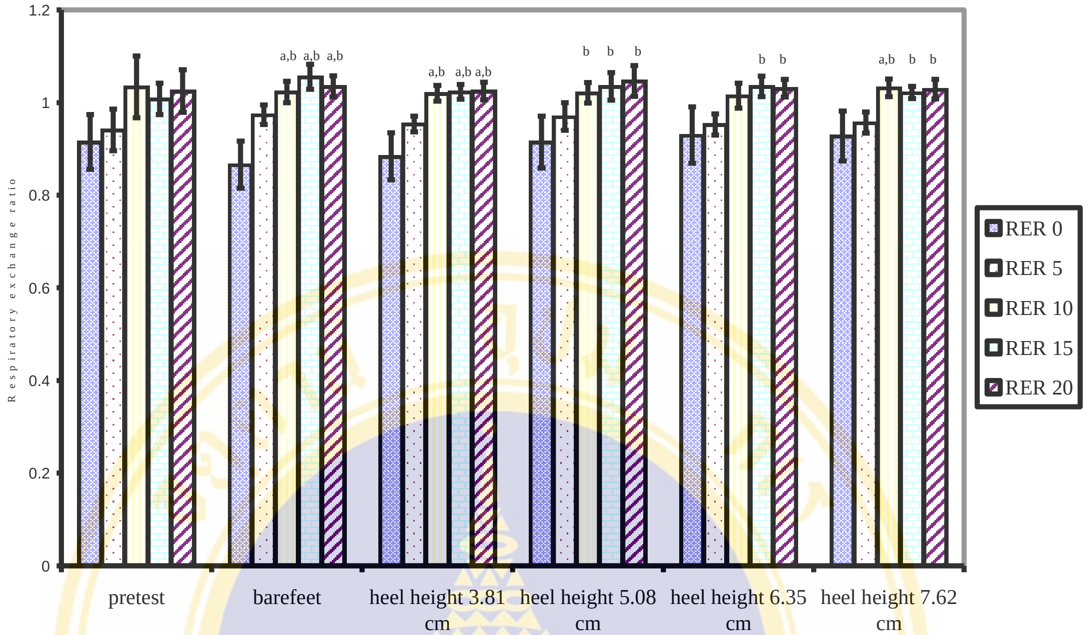

Figure 26 Comparison of the respiratory exchange ratio in pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm between minute 0, minute5th, minute 10th, minute 15th and minute 20th presented by mean ± SEM, statistical comparison shown were Repeated measure. Significant value $p < 0.05$. RER 0 = respiratory exchange ratio at minute 0, RER 5 = respiratory exchange ratio at minute5th , RER 10 = respiratory exchange ratio at minute10th, RER 15= at minute15th and RER 20 = respiratory exchange ratio at minute 20th. a = significant from minute 0, b = significant from minute5th,c = significant from minute10th.

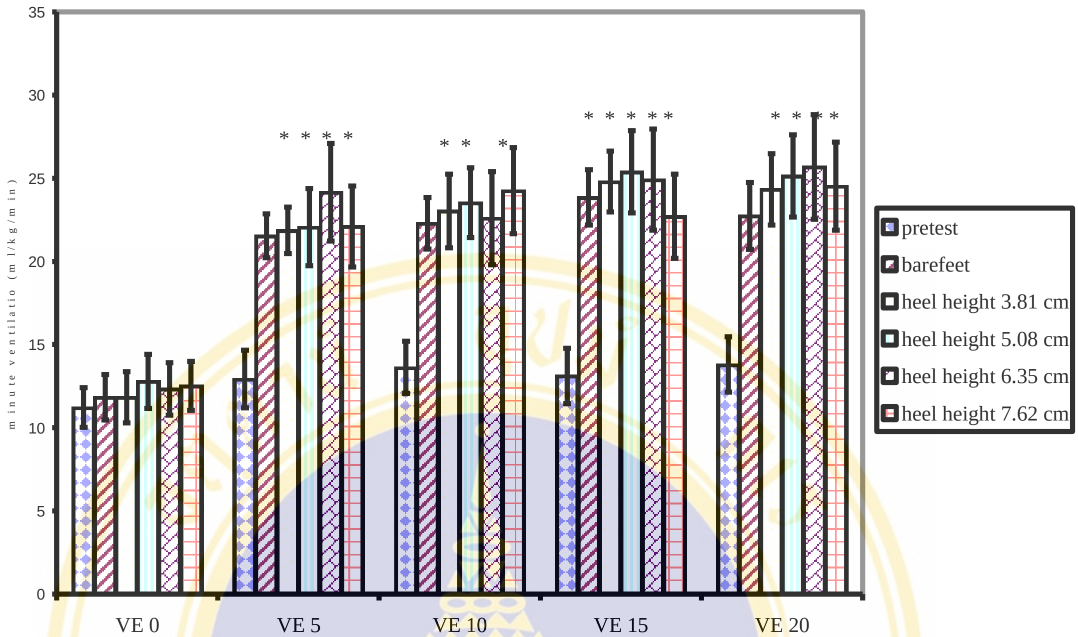

Figure 27 Comparison of the minute ventilation in minute 0, minute5th, minute 10th, minute 15th and minute 20th between pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm presented by mean ± SEM, statistical comparison shown were One way ANOVA. Significant value $p <$ 0.05. VE 0 = minute ventilation at minute 0, VE 5 = minute ventilation at minute5th, VE 10 = minute ventilation at minute10th, VE 15= minute ventilation at minute15th and VE 20 = minute ventilation at minute 20th. * = significant from pretest.

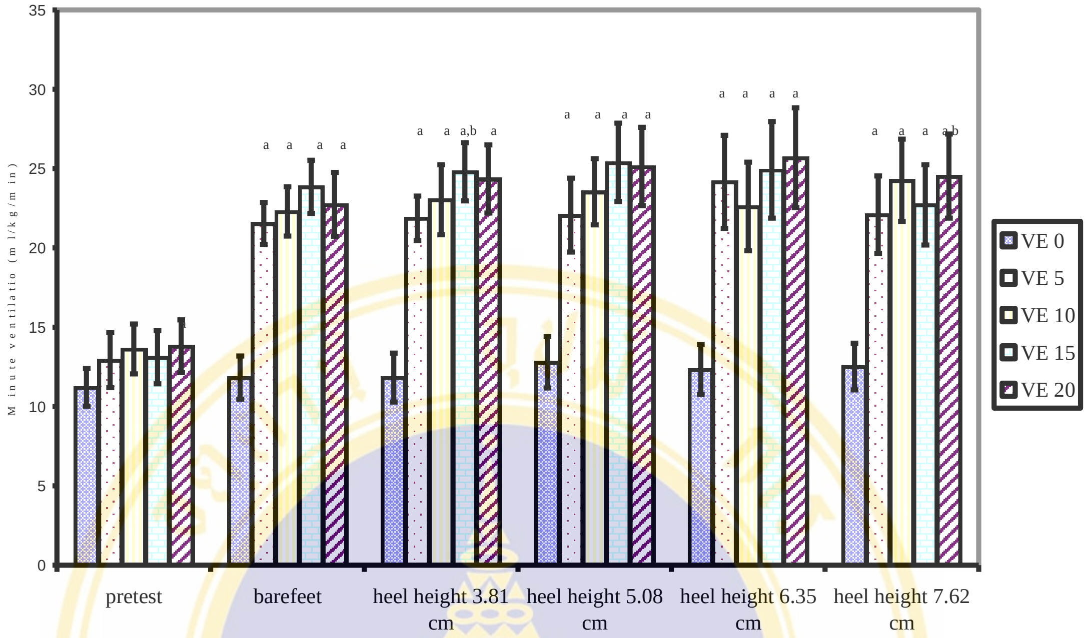

Figure 28 Comparison of the minute ventilation in pretest, bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm and heel height 7.62 cm between minute 0, minute5th, minute 10th, minute 15th and minute 20th presented by mean ± SEM, statistical comparison shown were Repeated measure. Significant value p < 0.05. VE 0 = minute ventilation at minute 0, VE 5 = minute ventilation at minute5th, VE 10 = minute ventilation at minute10th, VE 15= minute ventilation at minute15th and VE 20 = minute ventilation at minute 20th. a = significant from minute 0, b = significant from minute5th,c = significant from minute10th.

CHAPTER 5
DISCUSSION

5.1 Characteristics of subjects.

In this study, the physical characteristics of subjects (body weight, body height and body mass index) were in the range of normal Thai females (90) and the age of subjects had between 18 to 22years. By this age was nearly, because of the age has effect on gait characteristics. Winter and co-worker in 1990 (86) reported that there was difference of gait characteristics of elderly women and young women. All subjects in this study had normal arch of foot defined by the are under mid and fore foot (46).

All of subjects in this study were recruited from Collage of Sports Science and Technology, Mahidol University, it could be controlled their activities. From Nunutapornsak 2002 (61) and Opila-Correia in 1990 (65,66) found that there were no significant difference in ground reaction force between experienced and inexperienced wearers of high-heel shoes. But in this study, subjects were inexperienced wear high-heel shoes, because the experience of wearing high-heel shoes might be enough to influence the gait characteristics (62) and muscle strength (34). Most studies investigated the effects of high-heel shoes in low and high-heel shoes (7,27,61,79) by not specific in heel height, so in this study, the data were collected during walking with know heel height 3.81 cm., 5.08 cm., 6.35 cm. and 7.62cm.

5.2 The gait characteristic.

In this study presented gait characteristic of normal gait of young Thai females. By the step length and stride length were similar value with Jansen and co-worker in 1982 (41) because the body height of subjects had no difference. Whereas the step length and stride length of Blarke and co-worker in 1989 (7) had greater than this study maybe due to the differencing of body height and leg length.

5.3 The ground reaction force

The vertical ground reaction force, by the first peak of vertical ground reaction force (Fz_1) and the second peak of vertical ground reaction force (Fz3) had increased with high heel gait. Whereas, the vertical ground reaction force (Fz_2) had decreased with high-heel gait. By the result of present study agree with the study of Ebbelling and co-worker in 1994 (25), Snow and William in 1994 (79) and Nuntapornsak in 2002 (61). The first peak of vertical ground reaction force (Fz_1) had increased may be due to the greater plantar flexed position of the foot. By the normal gait, the eccentric of dorsiflexion could be absorbed the force during walking, whereas in high-heel gait the dorsiflexion could not eccentrically contracted (25). In the vertical ground reaction force (Fz_2) of high-heel gait was decreased may be due to the downward lift of the center of mass. Whereas in the second peak of vertical ground reaction force (Fz_3) of high-heel gait was increased may be due to the greater of potential energy during walking with high-heel shoes. When single support, the potential energy of high-heel gait greater than bare feet from the higher of center of mass. Therefore, during double limb support the kinetic energy was increased too.

The medial-lateral ground reaction force, by the second peak of medial-lateral ground reaction (Fy_2) had increased with high-heel gait may be due to the limit stability of gait during walking with high-heel shoes and the foot contact area was lesser than bare feet.

The anterior-posterior ground reaction force, by the first peak of anterior-posterior ground reaction force (Fx_1) was increased with high-heel gait. This present result was similar to the Ebbeling and co-worker in 1994 (25), Snow and William in 1994 (79) and Stefanyshyn and co-worker in 2002 (81).The larger braking force may be due to a greater deceleration of the center of mass. During walking with high-heel shoes had greater deceleration because the potential energy during walking with high-heel shoes greater than bare feet (PE = mgh). From conservation of energy, when the potential energy had greater, the kinetic energy had greater too ($KE = ½ mv^2$) (84). Whereas the second peak of anterior-posterior ground reaction force (Fx_2) was decreased with high-heel gait. This result of present study agree with the study of Nuntapornsak in 2001 (61). The decreasing of the second peak of anterior-posterior ground reaction force (Fx_2) may be the greater plantarflexion of foot (61). The inner length of gastrocnemius and soleous were not appropriate length. So it was affect on the force during push off phase.

5.4 Peak torque of hamstring, peak torque of quadriceps and h/q ratio

The peak torque of hamstring was decreased with the increasing of heel height, this may be due to the increasing the work of the hamstring muscle during walking with high-heel shoes. Because the swing limb during walking with high-heel shoes was greater deceleration than bare feet. Whereas hamstring muscle was decelerator of swing limb, so it worked hard to decelerated the swing limb (84). Whereas the peak torque of quadriceps had decreased with high-heel gait may be due to the center of mass had shifted forward and extra knee flexion when walking with high-heel shoes. However the h/q ratio had decreased with high-heel gait may be due to the decreasing of hamstring had greater than the decreasing of quadriceps. The result in this study contrast with the study of Stefanyshy in 2000 (81) may be due to the difference of subject, by the mean age around 32-49 years and they regularly wore high-heel shoes during their work day. It may be effect on the strength of muscle. This study the peak torque of hamstring and quadriceps were measured for the right side because a difference between sides in lower limbs in general population does not appear to be absolute according to most studies (14).

5.5 The energy profiles

There was mechanical change as there was increased in heel height, there were also changes in physiological changes. By the result of study agree with the study of Ebblling and co-worker in 1994 (25) and Mathew and Woonten in 1963 (57). In the presented, the heart rate, oxygen consumption, carbon dioxide output and minute ventilation were increased when walking in heel height of 3.81 cm., heel height of 5.08 cm., heel height of 6.38 cm and heel height of 7.62 cm. Between minute 0 to minute 5th, the rate of heart rate, oxygen consumption, carbon dioxide output and minute ventilation was reached a level sufficient to meet the energy demand of the tissue. By the heart rate, oxygen consumption, carbon dioxide output and minute ventilation also plateau and a steady state condition achieved. Measurement of rate of oxygen consumption at this time reflected the energy expenditure during the walking.

This increased cost of walking with high-heel shoes may be result from the biomechanical change imposed by the height of the heel such as the increasing of muscle work to control balance of movement during walking with high-heel shoes and the increasing of vertical displacement during walking with high-heel gait (49). But the energy expenditure in this study had no significant difference between high-heel gait and bare feet may be due to the step rate, it was controlled by the metronome, so the step rate during walking with high-heel and bare feet had no difference. Whereas the respiratory exchange ratios had no difference between bare feet and heel height conditions. By the increasing of carbon dioxide output indicated the proportionally increasing of oxygen consumption, but it was not different, it may be due to the height of heel and velocity of walking was not enough to influence for the energy expenditure. So during walking with high-heel shoes was utilized the nearly equal energy with the mid exercise and the equal efficiency during walking with difference high-heel may be due to the body could adapted for high-heel gait.

From this study, although the ground reaction force between bare feet and difference heel height had not significant difference, but the ground reaction force during walking with high-heel shoes were increased by heel height of 7.62 cm. was a great. It may be affecting on joint reaction force and may lead to degenerative joint change. Whereas, peak torque of hamstring and quadriceps, it had decreased after walking with high-heel shoes. So, wearing with high-heel shoes very long time or always, it may lead to the muscles strain of the lower extremity.

CHAPTER 6
CONCLUSION

In this study compared the ground reaction force, peak torque of hamstring and quadriceps, h/q ratio, and energy profiles. By the force plat form (AMTI) was used to detect the ground reaction force data, the isokinetics dynamometer (Lido) was used to collect the peak torque of hamstring and quadriceps and h/q ratio and the Vmax Series was used to collect and calculated the oxygen consumption, carbon dioxide output, respiratory exchange ratio and minute ventilation data.

The ground reaction, the first peak of vertical ground reaction force (Fz_1), the second peak of medial-lateral ground reaction force (Fy_2) and the braking force of anterior-posterior ground reaction force (Fx_1) were greater in high-heel gait than bare feet. Whereas, the vertical ground reaction force (Fz_2) and the first peak of medial-lateral ground reaction force (Fy_3) were less in high-heel gait than bare feet. Ground reaction force had no significant difference between heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm.

Comparison of peak torque hamstring and quadriceps and h/q ratio between bare feet and heel height conditions, by the peak torque of hamstring, peak torque of quadriceps and h/q ratio less in high-heel gait than bare feet, but no significant difference between bare feet, heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62 cm.

The energy profile of high-heel gait had greater than bare feet and pretest. By the heart rate, oxygen consumption, carbon dioxide output and minute ventilation of heel height 7.62 cm had greater than heel height 6.35., heel height 5.08 cm., heel height 3.81 cm. and bare feet, respectively. So during walking with high-heel shoes had used the energy more than bare feet.

For further study, the foot pressure distribution and the electromyography (EMG) activities of back and lower extremity muscles during high-heel gait are interesting to investigate. It is interesting to study about the relationship between height of heel, on injury, degenerative and abnormality of lower extremity.

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APPENDIX

APPENDIX A

Experimental project of the study

Subject recruitment

Questionnaires (General health, physical activities and wearing shoes behaviors)

Informed consent signing

↓

Anthropometrics measurement

(Body weight, body height, range of motion, footprint, size of shoes)

↓

Study effects of high-heel shoes on energy profile on treadmill (around 25 minute)

↓

Study effects of high-heel shoes on GRF by walked on force plate form

(around 25 minute)

↓

Study effects of high-heel shoes on peak torque of hamstring and quadriceps

(around 5 minute)

↓

Rest around 24 hours

APPENDIX B

Calibration of Instrumentation

1. Vmax229 Pulmonary Function/ Cardiopulmonary Exercise Testing Instrument

The gas analyzer (Vmax 229) had three calibration procedures (Volume calibration, Gas calibration and Gas set up). By the 3.0 liter calibration syringe was performed volume calibration and verification. The calibration syringe attached to the mass flow sensor and performed five strokes for calibration and verification. The volume calibration was performed before testing every time. The gas calibration, by attached the sample line to the calibration fitting on the front of the Pneumatics module. Sample three gas concentration were cal 1 gas (16% oxygen, 4% carbon dioxide), cal 2 gas (26% oxygen, 0% carbon dioxide) and room air (20.94% oxygen, 0.05% carbon dioxide). In the end, re-connection of the sample line attached to the sample fitting on the mass flow sensor. The volume calibration was performed before testing every day. The value of gas setup was corrected by the setup menu. The value of setup was presented in Table 12.

Table 12 The values of gas setup of Vmax229.

Gas Variable	Value	Gas Variable	Value
Dir	0.027	O_2	1.496
El	0.799	CO_2	0.100
Pm	-0.001	CH_4	2.837
Pb	-3.599	C_2H_2	4.530
Tewp	2.602	CO	2.650
Pbar	7.601	ECG1	-3.107
Epd	2.829	ECG2	0.756
Ehot	2.539	POD1	-0.067
Ecold	2.550	POD2	-0.054
Ecom	0.988	POD3	-0.059
5/Rs	5.029	POD4	-0.054
-15	-15.361	POD5	-0.060
+15	15.214	POD6	-0.053
Vol	-6.950	POD7	-0.060
		POD8	-0.057

APPENDIX C

Figure 29 Isokinetics machine (Lido Multi-Joint II, Loredan Biomedical, Inc.,CA)

Figure 30 Isokinetics machine (Lido Multi-Joint II, Loredan Biomedical, Inc.,CA)

Figure 31 Treadmill (2000 Treadmill, SensorMedics,USA)

Figure 32 Oxygen analyzer (Vmax Series, SensorMedics,USA)

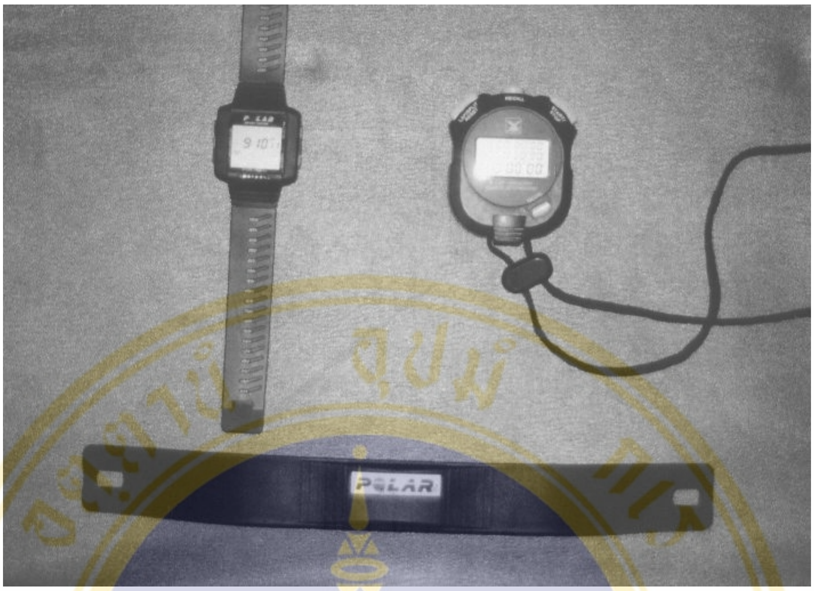

Figure 33 Polar (F-PLC, Finland)

Figure 34 A force plate with 60x40x10 centimeters in size (AMTI)

Figure 35 Force analysis program and AD converter control unit (AMTI)

Figure 36 High-heel shoes (heel height 3.81 cm., heel height 5.08 cm., heel height 6.35 cm. and heel height 7.62cm

APPENDIX D

หนังสือยินยอมให้ทำการวิจัยโดยรับการบอกกล่าวและเต็มใจ
(Informed consent form)

ชื่อโครงการ "ผลของความสูงรองเท้าส้นสูงต่อการเปลี่ยนแปลทางชีวกลศาสตร์ของระยางค์ส่วนล่างและการใช้พลังงานในวัยรุ่นไทยเพศหญิงขณะเดินด้วยความเร็วคงที่" (Effects of differencing heel heights on the lower limb biomechanics and energy profiles of young Thai females during constant speed walking)

วันให้คำยินยอม วันที่........... เดือน.................................พ.ศ. ....

ก่อนที่จะลงนามในใบยินยอมทำการวิจัยนี้ ข้าพเจ้าได้รับการอธิบายจากผู้วิจัยถึงวัตถุประสงค์ของการวิจัย วิธีการวิจัย อันตราย หรืออาการที่อาจเกิดขึ้นจากการวิจัย รวมถึงประโยชน์ที่จะเกิดขึ้นจากการวิจัยอย่างละเอียด และมีความเข้าใจดีแล้ว

ผู้วิจัยรับรองว่าจะตอบคำถามต่างๆที่ข้าพเจ้าสงสัยด้วยความเต็มใจ ไม่ปิดบังซ่อนเร้น จนข้าพเจ้า

ข้าพเจ้าเข้าร่วมการวิจัยโดยสมัครใจและมีสิทธิที่จะยกเลิกการเข้าร่วมการวิจัยนี้เมื่อใดก็ได้

ผู้วิจัยรับรองว่าจะเก็บข้อมูลเฉพาะตัวข้าพเจ้าเป็นความลับ และจะเปิดเผยได้เฉพาะในรูปแบบที่เป็นการสรุปผลการวิจัย กรเปิดเผยข้อมูลที่เกี่ยวกับตัวข้าพเจ้าต่อหน่วยงานต่างๆที่เกี่ยวข้อง กระทำได้เฉพาะในกรณีจำเป็นด้วยเหตุผลทางวิชาการเท่านั้น

ผู้วิจัยรับรองว่าหากเกิดอันตรายใดๆอันเนื่องมาจากการวิจัยดังกล่าว ข้าพเจ้าจะได้รับการรักษาพยาบาลโดยไม่คิดมูลค่าตามมาตรฐานวิชาชีพ และจะได้รับการชดเชยรายได้ที่สูญเสียไประหว่างการรักษาพยาบาลดังกล่าว ตลอดจนเงินทดแทนความพิการที่อาจเกิดขึ้น

ผู้วิจัยรับรองว่าหากมีข้อมูลเพิ่มเติมที่ส่งผลกระทบต่อการวิจัย ข้าพเจ้าจะได้รับการแจ้งให้ทราบโดยไม่ปิดบังซ่อนเร้น

ข้าพเจ้าได้อ่านข้อความข้างต้น และมีความเข้าใจดีทุกประการและได้ลงนามในใบยินยอมนี้ด้วยความเต็มใจ

ลงชื่อ...(ผู้ยินยอม)

ลงชื่อ...(พยาน)

ลงชื่อ...(พยาน)

ชวนพิศ บุญเกิด

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